UNDERSTANDING THE PERSISTENCE OF THE TROPOSPERIC OZONE PROBLEM IN THE U.S.: IS OZONE A POLLUTANT FOR THE RICH?

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Shannon M. Larsen

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UNDERSTANDING THE PERSISTENCE OF THE TROPOSPERIC OZONE PROBLEM IN THE U.S.: IS OZONE A POLLUTANT FOR THE RICH?

Shannon M. Larsen, Ph. D.

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Tropospheric (ground level) ozone continues to be a problem in many U.S. metropolitan areas. Unlike other constituent pollutants regulated by the Clean Air Act ozone is odorless and tasteless and can only be perceived by the naked eye at high enough concentrations to be considered "smog." This analysis explores reasons why after 30 years of regulatory effort some metropolitan areas still fail to attain federally mandated standards. I consider both sources of supply of ozone and the role of technological innovation in reducing ozone levels as well as socioeconomic trends that drive demand for services and amenities that contribute to the ozone problem. A class of Producer Services is highly correlated with ozone levels and this relationship provides insight into the complex socioeconomic drivers of the ozone problems.

The Environmental Kuznets Curve (EKC) is a useful framework employed to understand the trajectory of ozone levels. While ambient levels of the pollutant have declined significantly, I show evidence that ozone is not perceived as a sufficient "disamenity," even at the highest income levels, to drive further reductions. I hypothesize that the status quo is likely to persist in the absence of a new regulatory approach and suggest a modified EKC that might inform future discussions.

Methodological and spatial data issues are also discussed with special focus on those problems found when using both socioeconomic and environmental data. Kriging and cluster analysis are investigated and I suggest these methods as promising

directions to improve quantitative methods available to social scientists interested in the interaction between the economy and environmental systems.

BIOGRAPHICAL SKETCH

Shannon Larsen received a B.A. in International Relations at Lewis and Clark College in Portland Oregon in 1991 and a Masters in Regional Planning from Cornell University in 1999. During the 1991 to 2004 time period she spent 9 years in Southeast Asia working in a refugee organization, an oil firm, and with The Boston Consulting Group. The intermediate years, 1997 to 2001 were spent studying at Cornell, focusing on environmental planning in metropolitan areas.

She is currently Executive Director of Development and Corporate Relations at the Santa Fe Institute serving as a bridge between SFI's academic and business communities, organizing topical meetings and collaborative research engagements. She also facilitates research between U.S.-based researchers and select international scientists and reviews funding applications to support research and academic meetings in developing countries. Her travel has taken her to over thirty countries and she is presently pursuing international research on best practices for public and private research and development funding strategies that promote innovative and transformative research.

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LIST OF ABBREVIATIONS

*ACS**	Advanced Consumer Services
EKC	Environmental Kuznets Curve
EPA	Environmental Protection Agency
ITP	Income Turning Point
MFG	Manufacturing
MSA	Metropolitan Statistical Area
NAAQS	National Ambient Air Quality Standards
NEW MET	New Metropolitan
NON-MET	Non-Metropolitan
NOx	Nitrogen Oxide
OMB	Office of Management and Budget
PSFIN	Producer Services Financial
PCPI	Per Capita Personal Income
PSOTH	Producer Services Other
RACT	Reasonably Available Control Technology
RIA	Regulatory Impact Analysis
SO_2	Sulfur Dioxide
SIP	State Implementaton Plan
TSP	Total Suspended Solids
VMT	Vehicle Miles of Travel
VOC	Volatile Organic Compound

**Variable names are in italics*

CHAPTER 1

INTRODUCTION

1.1 Overview

Air pollution in the U.S. decreased significantly in the thirty years following the promulgation of the Clean Air Act. Yet the dramatic improvement in air quality cannot be attributed solely to the Clean Air Act rules and regulations designed to limit emissions of various constituent pollutants. Coinciding with the implementation of the Act, the U.S. economy experienced a structural shift from a primarily a manufacturing-based economy to a service-based economy -- as manufacturing activity declined so did average ambient levels of air pollution. At the same time the average income of U.S. citizens increased, or at least remained flat, in real terms and consumers began to demand a better quality of life.

However, a perplexing and challenging problem persists and has received much less academic attention. After 30 years of regulation air quality has improved consistently for each pollutant regulated by the U.S. Environmental Protection Agency (EPA) except one, Tropospheric Ozone (O_3)[1] for which the rate of improvement is much less impressive in spite of continued regulation and improvements in U.S. economic performance. In 2006, 455 out of 3011 counties failed to attain the ozone standard set by the EPA compared to only 45 for Lead. It is difficult to disentangle the relative effect of the regulations as a whole but levels of ozone remain dangerously high in many metropolitan areas, especially, and possibly surprisingly, in those areas that are also the wealthiest. So while the overall story of air pollution and economic performance in the U.S. is largely consistent with existing theory--air quality improved with economic growth and manufacturing decline was accompanied by a

[1] Tropospheric ozone should not be confused with stratospheric ozone. Stratospheric ozone is considered “good ozone” because it shields the earth from harmful ultraviolet radiation from the sun.

decrease in air pollution--the case of ozone fails to conform. This study explores why this is the case. The explanation rests on understanding how the transition from a manufacturing economy changed both the urban built environment and consumer's interaction with their environment. In a service-oriented economy consumers, not just producers, become significant sources of supply of the pollutants that create ozone.

The industries that replaced manufacturing relied on human capital rather than goods production to generate wealth. Since service industries do not produce significant amounts of air pollution it was reasonable to expect air pollution to decline with manufacturing. However, the secondary activities that accompany a wealthy service-oriented economy such as motor vehicle and airplane travel, air-conditioning, dry-cleaning and modern amenities such as snow and leaf-blowers, weed-eaters and lawnmowers increased and became unexpected new sources of emissions. The primary emissions problem is no longer "point sources" of emission (eg. a manufacturing plant), but the hundreds, thousands or millions of smaller emitters, known as "non-point" or "area" sources. The most significant area source is now motor vehicle travel and any public policy makers knows that regulatory and enforcement efforts become much more complex when emissions come from non-point sources.

It is also reasonable to assume changes in the structure and characteristics of urban area in recent decades exacerbated the problem. Population growth, socioeconomic changes, lower transportation costs and land use changes that led to the sprawl of America's cities and contributed to an increase in total miles traveled. The U.S. Department of Transportation estimates total Vehicle Miles Traveled (VMT) in the U.S. increased from 1.5 billion miles in 1981 to 3 billion miles in 2005. With a projected growth rate of at least 2-3% annually through 2030 the problem of vehicular emissions will persist.

While these factors combined might explain why the supply of ozone has not decreased to the extent predicted by policy-makers there are contributing explanations on the demand side as well. The analysis that follows presents evidence that there is a symbiotic relationship between environmental quality, economic performance and the broad class of the service sectors termed producer services. Counties whose total wage bill is comprised of a relatively large proportion of wages from the high-end services sector, and by extension a lower than average representation from the manufacturing sector, not only do well economically, but also tend to be the counties that have failed to meet ozone standards for at least a decade. Not surprisingly these are also the counties that experienced significant population growth. This prompts a somewhat peculiar initial hypothesis: counties that that fail to attain the ozone standard (*i.e.* are the most polluted) do better economically than their peers *and* also attract companies that hire employees who demand a high quality-of-life offering (Glaeser *et al.* 2001a).

To begin to explain this apparent anomaly it is important to understand the incentives that typically contribute to the reduction of pollutants, and explain why the case might be different for ozone. Ozone is an odorless and tasteless gas formed from the chemical combination of nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. Ozone is the major component of what is broadly defined as "smog." Since ozone is not directly emitted into the air, it is not directly regulated by the NAAQS, but is controlled through the regulation of NOx and VOC emissions. Ozone has been determined to be harmful to human health because it damages lung tissue, reduces lung function and sensitizes the lungs to other irritants. Long-term exposure can lead to aggravated asthma and permanent lung damage. Nevertheless ozone may not be perceived to be a threat because at moderate levels ozone is odorless and tasteless and the symptoms of exposure to unsafe levels of ozone may well be ascribed to other factors or considered an inevitable inconvenience of urban living.

An "urban amenity" (hitherto referred to as "amenity") as defined by Glaeser *et al.* (2001a) is a part of a package of goods demanded by consumers of urban space. Amenities, together with lifestyle options and the of the *creative class* have been found to be important attractors of a highly skilled workforce (Florida 2002). On the other hand, pollutants are almost always considered a "disamenity" such that more is worse, not better, and economic theory posits that as incomes increase, consumers will demand, and are often willing to pay for, the opportunity to have less of the disamenity. If ozone is indeed a disamenity then consumers should demand less ozone as incomes increase. Preliminary evidence suggests this may be true—but only to a point—after which there seems to be no discernible consumer behavior that would indicate ozone is considered a disamenity. In other words, studies find measurable preference for the absence of ozone only at the highest levels where ozone can be perceived as a nuisance. Findings from other pollutants, such as toxic releases, may provide some insight as to why this might be the case. A recent study shows that the level of toxicity is an important factor in specifying the income/pollution relationship, or put another way, not all pollutants are perceived as equal threats in the eyes of the consumer (Emerson and Pendleton 2004).

Since it is not clear that ozone is always a disamenity this study explores the hypothesis that while the *absence* of ozone can be considered an amenity but the corollary is not true, the *presence* of ozone is not considered a sufficient disamenity such that citizens are willing to pay more to avoid ozone. The validity of the first assertion, that the *absence* of ozone can be considered an amenity, has been shown to be true in Los Angeles, an area where ozone problems are among the most severe in the nation. Kahn (2000) showed that controlling for local labor market demand, home prices and other county attributes, decreased ozone levels were correlated with population growth. His analysis also provides modest evidence for the second assertion, that the *presence* of ozone is not a disamenity. In counties in the San Bernardino metropolitan area where ozone levels declined over time, housing prices remained steady as the area experienced an increase in amenity-seeking migrants such as retirees and college graduates.

While it is possible to continue to test this hypothesis on a place-by-place basis the challenge is to generalize these findings to determine how economic actors perceive the presence of ozone, in relation to other economic or amenity choices. The Environmental Kuznets Curve (EKC), a theoretical model commonly employed in the environmental economics literature, provides a useful context for discussing the relationship between income and levels of pollution. The EKC posits that income and pollution form an inverted U-shaped curve when income is plotted on the horizontal axis against levels of pollution (or emissions) on the vertical axis. The concept suggests that pollution levels will increase during early phases of economic development, decline when income reaches some critical inflection point, and trend towards zero (perhaps to the point of being imperceptible) as the society becomes wealthier (see Figure 1.1).

In many ways this theory is intuitive, one would expect increased demand for clean air and water as a population becomes wealthier and more educated. Yet since costs are not represented here it is not reasonable to assume people will value a reduction in pollution regardless of cost. In a service economy costs may manifest themselves not just as the actual cost of reducing the pollutant but also as an implicit "tax" on other more highly valued aspects of "quality of life."

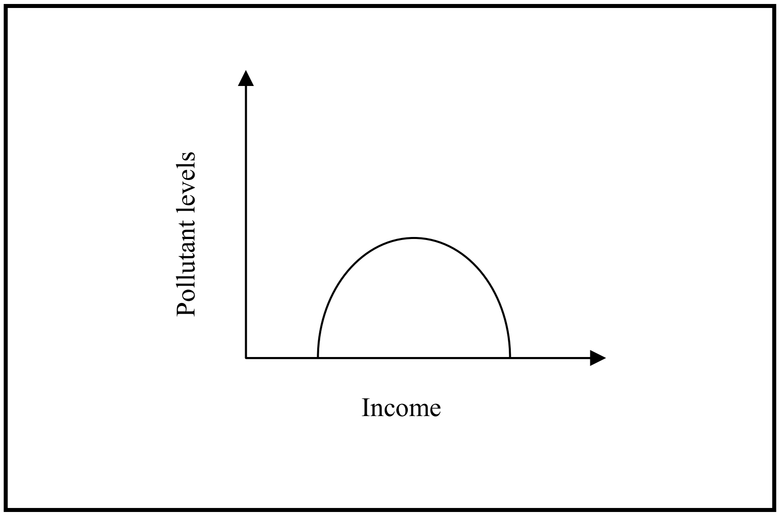

Figure 1.1. Hypothetical Environmental Kuznets Curve (EKC)

This study explores possible reasons why the EKC does not appear to hold for ozone, *e.g.,* why ozone levels are not declining significantly with wealth, and suggests that for a nearly barely visible pollutant such as ozone, advanced societies such as the U.S. may not value a reduction in ozone over other amenities. The schematics in Figures 1.2 and 1.3 illustrate the hypothesis.

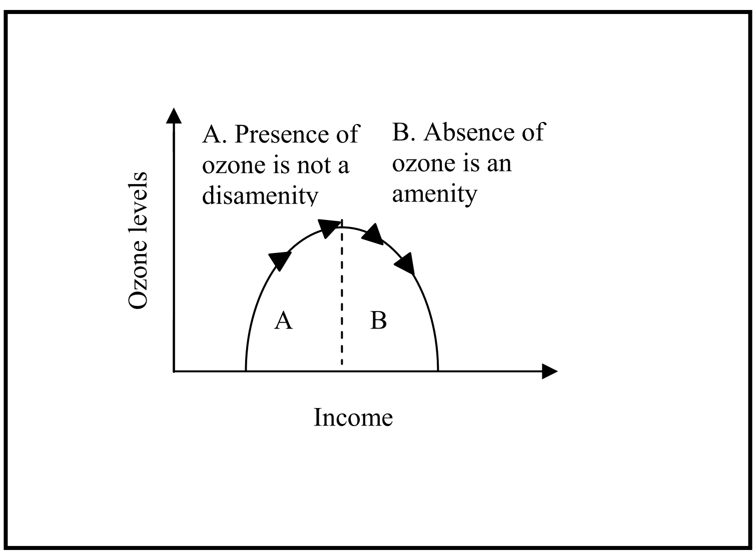

Figure 1.2 Hypothetical EKC when absence of ozone is an amenity

The implication is that if the *absence of ozone* is not as perceived as a significant urban amenity, there will not be sufficient consumer demand for further reductions in ozone to drive levels towards zero. As income increases, the EKC will be expected to flatten at a given level of ozone. At this state, consumers may be willing to accept some level of inconvenience and a known but conceptually vague threat to their health. In the absence of further regulatory or public intervention, there would be little reason to expect further reduction in ozone levels, even as incomes rise.

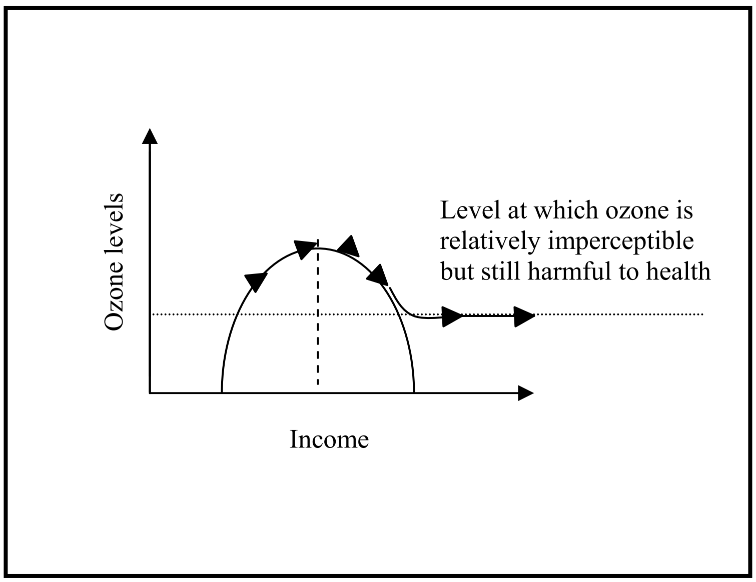

Figure 1.3 Hypothetical EKC when absence of ozone is not considered an amenity

Using empirical analysis I examine trends from both the supply and demand sides of the pollutants that combine to form ozone to develop a theoretical framework to begin to predict the trajectory of ozone pollution in the future. A suite of methodological approaches are employed to begin to test this framework ranging from standard empirical data analysis techniques to linear regression and spatial statistics methods such as kriging and cluster analysis. Methodological and data issues that precluded a full test of this hypothesis are discussed explicitly in context to guide future research.

The totality of the study provides insight for future research. By examining ozone from a more comprehensive national perspective we begin to understand how the ozone problem will evolve as the U.S. economy continues to transform into a service-based, information society. This comprehensive approach is important for two reasons. First it will assist with developing policies and programs designed to work within the current incentives, preferences and structural dynamics of the current U.S. system. Second it will provide useful knowledge to countries that are just entering the stage of development the U.S. experienced in the 1970's. As individuals become wealthier in countries just beginning to transition to a service-based economy there is emerging demand for pollution reduction. Environmental planners and policy makers are beginning to develop the regulatory mechanisms to achieve cleaner air and a simple recommendation is to acknowledge that citizens do not react to ozone pollution in the same manner as other constituent pollutants. Education on the health effects of high ozone levels is important and should be started very early in the policy-making and regulatory process.

1.2 Background

In the 1960s severe pollution problems such as the burning of the Cuyahoga River in Ohio, smog-filled cities and reports of dangerous levels of lead in children's blood focused public attention on the imminent and potential hazards of both air and water pollution to human health and safety. The resultant legislation, namely The Clean Water Act, The Clean Air Act and the National Environmental Policy Act, brought about dramatic improvements in environmental quality largely achieved by promulgating rules which forced the most sizeable polluters to control emissions or face penalties. As a result of the Clean Air Act in 1970 the U.S. EPA set the National

Ambient Air Quality Standards (NAAQS) that identified maximum ambient concentration levels considered safe for humans. The six regulated constituent pollutants were Sulfur Dioxide, Carbon Monoxide, Lead, Nitrogen Dioxide (NOx) and Particulate Matter. State and local regulatory and enforcement agencies were charged with maintaining pollution levels at or below the standard. Over thirty years later the most significant sources are largely regulated so further reductions in pollution levels will only come from incremental emissions reductions from smaller, and often geographically dispersed, polluters. Regulating non-point source polluters is a more persistent and intractable issue for two reasons. First, for consumers, complying with regulations typically requires investment in new technology or a change in behavior, or both. There is a practical hurdle of educating and motivating the public about the need for compliance and enforcement is simply more difficult when there are many small polluters. Second, economies of scale are less likely to apply so the marginal costs to society of reducing each additional increment of pollution may increase.

With regard to ozone, the non-point source problem is particularly acute because ozone is not emitted directly into the air but is formed through the chemical combination of volatile organic compounds (VOC) and Nitrogen Oxides (NOx) when sunlight is present. The emission of NOx is monitored and controlled through the regulatory mechanisms available to states in order to comply with the NAAQS. VOCs are monitored and controlled because they are a component of ozone but the sources are very diverse ranging from chemical manufacturing to dry cleaners, paint shops and other sources that use solvents. Efforts to control VOC emissions range from the reformulation of gasoline to the requirement of manufacturing plants in areas that fail to comply with the ozone standard to install "Reasonable Available Control Technology (RACT)." RACT requirements are negotiated on a case-by-case basis and are intended to reduce emissions without placing undue economic burden on plants.

The Unfunded Mandates Reform Act of 1995 required that all federal agencies "select from a reasonable number of regulatory alternatives the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule and is consistent with law or to explain why such an alternative was not adopted."[2] In essence this required that regulations balance the costs and benefits of rules designed to protect the environment and opened the door for an entirely new cottage industry of cost-benefit analysis. Yet the system is not set up to capture the broader trends of the relationship between pollution and economic performance. For example, prior to promulgating a regulation, the U.S. Environmental Protection agency (EPA) issues a Regulatory Impact Analysis (RIA) that models the economic impact for the proposed regulation on the affected industries only, but not the economy overall.

The U.S. EPA compiled the evidence to date on the costs and benefits of the Clean Air Act in 1997, describing the central research question on their website:

> "Throughout the history of the Clean Air Act, questions have been raised as to whether the health and environmental benefits of air pollution control justify the costs incurred by industry, taxpayers, and consumers. While the benefits and costs of individual programs and standards continue to be addressed through narrowly-focused regulatory analyses, there has never been a comprehensive, long-term, scientifically valid and reliable study which answered the broader question: How do the overall health, welfare, ecological, and economic benefits of Clean Air Act programs compare to the costs of these programs?" (US EPA 2000; 242).

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[2] Under this act, agencies were required to: to perform a cost-benefit analysis; to make "a reasonable determination, based on the rule-making record as a whole" as to whether the rule is likely to provide benefits that justify the costs and whether it "is likely to substantially achieve the rule making objective in a more cost-effective manner, or with greater net benefits, than the other reasonable alternatives considered by the agency;" to conduct a risk assessment; and to provide for peer review of risk assessments and, if the rule is likely to cost more than $500 million, of the economic analysis (Federal Register 2001).

Quantification of the benefits of a clean environment on economic performance may not yet be captured fully in the academic literature, but there is ample evidence that, at least on a local level, the relationship between pollution and economic growth is being considered. Examples abound in the popular press of the message that pollution does not pay for urban areas. For example, Houston's business development manager states:

> ". . .ultimately, the same economic self-interest that fueled Houston's unchecked growth is shaping its response to its air quality problems. In a new economy that prizes "clean" industries over polluting manufacturers, Houston's is at a competitive disadvantage. Local technology companies are finding it harder to recruit employees, while business leaders fear that the city's image as the "pollution capital" is hurting its efforts to recruit companies and industries." (New York Times 2000)

A 1992 *Money* Magazine survey of their generally affluent readership sought to determine the characteristics people value in choosing a place to live. The top three criteria, in order of importance were clean air, low crime and clean water. Similarly, *INC Magazine* cites a study by Cognetics, Inc. identifying the top criteria for determining the best places to start and grow a business. Among the top five was the rather nebulous condition, "*must be a nice place to live"* (Barker 1999).

Leaders in developing countries are also noticing the linkage between the environment and economic performance. In fact, the link between pollution and the economy in the developing world may be even more pronounced as the intensity of the pollution translates into even more devastating and tangible effects on health and worker productivity. For example, The World Bank estimated that in the late 1990s China lost between 3.5% and 7.7% of its potential economic output as a result of the health effects of pollution on the country's workforce (World Bank 1997). Yet amid an assortment of largely unenforceable environmental regulations, metropolitan areas in China are taking action in trying to enhance their local economy by cleaning the environment. Hong Kong's Prime Minister, Tung Chee Hwa, considered Hong Kong's competitive position relative to other cities weakened by pollution, "Hong Kong is to spend HK$ 30bn (£2.3bn) to clean up its environment in response to criticism from multinationals which say its polluted air and water threaten its competitiveness" (Financial Times 1999). More recently, the deputy Mayor of Taiyuan, one of the earliest centers of Chinese civilization, proclaimed "(w)ithout clean air, we simply cannot consider our city civilized" (Economist 2002).

The relevance of ozone and the specific case of ozone regulations is equally relevant and pressing in the U.S.. The attainment regulations can be seen as a deterrent to growth as new plants in certain industries are either prohibited from locating in counties subject to attainment regulations or choose not to do so, for fear of future expenses and problems. The Mayor of Chattanooga, Tennessee, Bob Corker, claimed to be "panic-stricken" when the city failed to meet attainment regulations. In public comments, he made a very direct connection between the regulations and their short-term economic implications, "If you're not in attainment, there are all kinds of industries that you cannot recruit into your community." He went on to say, "(a)ll of a sudden, we've got 3,000 acres of industrial land and 1,200 acres (of it) with the infrastructure already in, and the interchange being built to it, and we're out of business." Part of the community strategic plan to reduce ozone levels was to reduce vehicle emissions by introducing mandatory testing and enforcement of emission control rules. Corker admitted that "(n)obody in the community likes (testing), but everybody in our community wants good-paying jobs" (Fowler 2005).

1.3 Outline

This study offers a view on the relationship between ozone pollution, regulations, economic performance and the structural changes in the economy which precipitated economy/environment relationship at one level of abstraction higher than the current literature. Most studies focus on three topical areas: investigating the effect of ozone regulations on firm location and investment decisions; determining the impact of ambient concentrations of ozone on specific populations (*i.e.,* health-related analyses) and the evaluating the impact of regulations on a specific region. Yet because we still know relatively little about the overall economic and socioeconomic composition of areas emitting high levels of ozone, this analysis provides a careful empirical portrait both of county level characteristics of areas with varying ozone levels and the associated levels of stringency of regulations and answer the following questions: Why does the ozone problem persist? Why have the ozone regulations not solved the ozone problem? How has the transition to a service-based economy changed the nature of the ozone problem, if at all? What are the trends that may affect the persistence of ozone problems in metropolitan counties and are there policy mechanisms that could be exploited? Can we use this information to predict both of the future trajectory of the U.S. ozone problem?

Following this introduction, I review literature relevant to this study. The literature is a broad representation from a number of fields including urban economics, environmental economics, public policy analysis, and development studies. In Chapter 3 I describe the data used in this analysis and the taxonomies created to segment the data across temporal and geospatial dimensions. Chapter 4 discusses challenges of matching environmental and economic data sets and I review suggested remedies and discuss the relevance of data issues to the present analysis.

Chapter 5 begins the analytical section and a conceptual framework (see Figure 1.4) helps to illustrate the hypothesized causal links between various interacting factors of the ozone problem. The direction of the arrows shows the hypothesized direction of causality with a dotted line indicating a weak link and a solid line indicating a stronger relationship. A simple narrative is that in a manufacturing-dominated economy the manufacturing activity itself is the significant source of supply for ozone while in a services-dominated economy it is the economic activity surrounding the services sector that actually generates the supply. The link to the built environment is the obvious difference; the infrastructure necessary to support a service-oriented economy is dramatically different from that necessary to support a manufacturing economy.

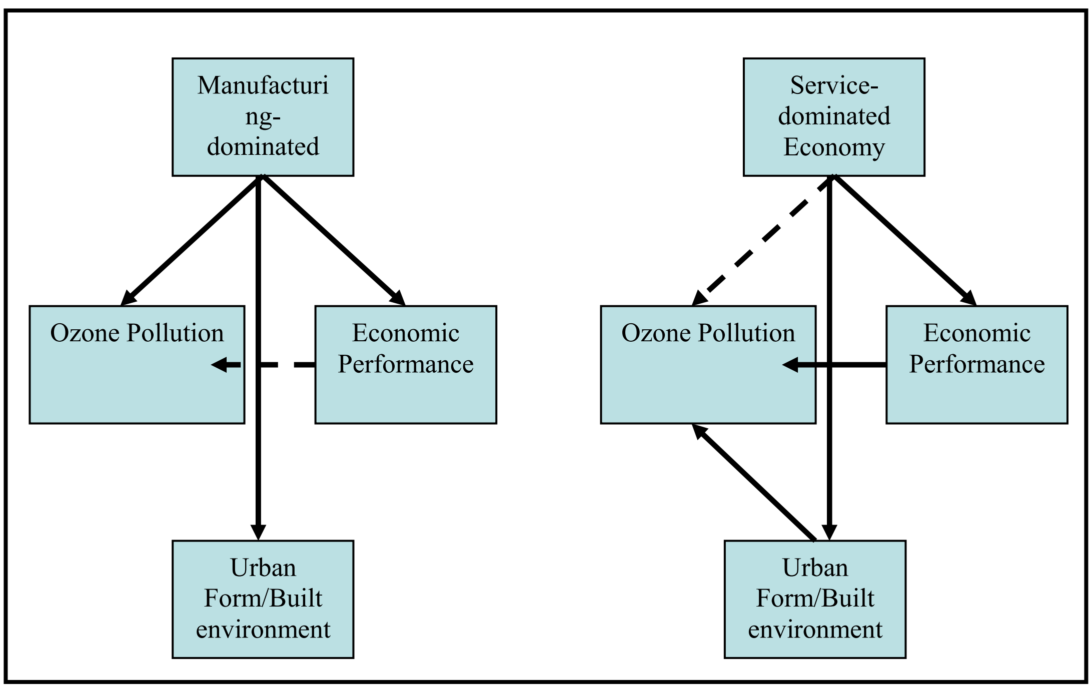

Figure 1.4 Conceptual schematic of differences in manufacturing and service economies

In Chapter 5 I present historical data in production of emissions, thus providing a basis from which to discuss possible future trends. Industry lifecycle curves share that those counties that transitioned to a service economy *faster* have more severe ozone problems. In addition, producer services are highly correlated with elevated levels of ozone indicating evidence that the sectoral shift to a service-based economy changed the sources of supply of ozone. The second part of the chapter explores how these relationships have differed according to urban form.

To examine trends affecting the demand (or lack thereof) for ozone-free living the analysis in Chapter 6 identifies the characteristics of the a county that may explain the correlation between producer services and high levels of ozone. The demand for a high quality of life features prominently in the discussion. Figure 1.4 is enhanced in Figure 1.5 below to include the hypothesized relationship between amenities and other factors interacting to contribute to the persistence of an ozone problem. Again, the relationship and direction of the causality is different for manufacturing and service-based economies.

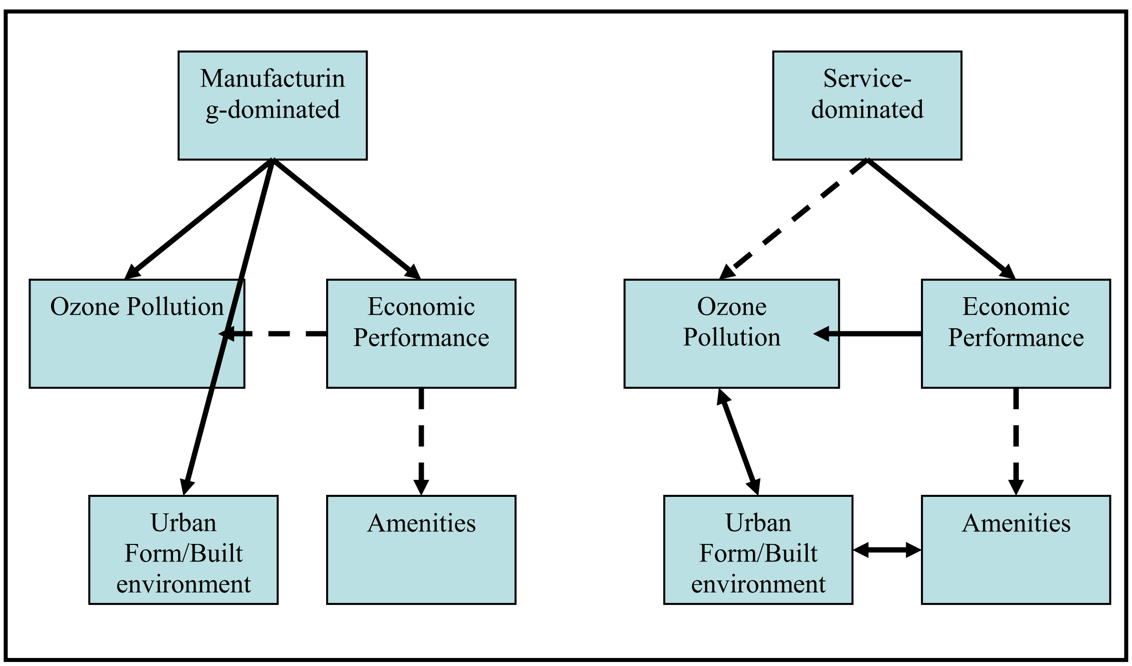

Figure 1.5 Conceptual schematic of differences in manufacturing and service economies considering the Amenity Factor

Chapter 7 examines whether ozone is a disamenity for urban consumers. Using a revealed preference model explaining housing prices and population growth the results show that the presence of ozone regulations is not a negative determinant of both metrics of urban growth but high ozone levels are associated with modest declines in both housing prices and population growth. This indicates a marked change from the manufacturing based economy where preferences for amenities were not as significant.

Chapter 8 summarizes the results and discusses the implications for the fact that only at certain levels is the presence of ozone perceived to be a disamenity and therefore many traditional regulatory and economic incentives for pollution reduction may not be applicable for the case of ozone. The combination of the physical characteristics of ozone and its relatively benign short-term and indirect effects on human health may diffuse concerns of the public. Traditionally the drivers of demand for pollution reduction, high-income communities are complicit in accepting ozone's persistence. This has particular relevance in predicting the demand for reduced ozone levels in the future and crafting policy recommendations that drive further reductions. This understanding will undoubtedly immediately transfer to countries on the threshold of major structural adjustments in developing economies.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The persistent debate about the relationship between environmental quality, the regulations that promote and maintain that quality and economic growth, has fostered a broad and vibrant literature base. The studies relevant to this analysis can be broken down into four general categories. First and most prevalent are studies that estimate the cost-benefit tradeoffs of specific regulations. The underlying goal is to determine if the quantifiable benefits to society of compliance with air quality regulations outweigh the costs imposed on firms. This provides useful background information to set the context for this analysis, but for reasons discussed below, has limited utility in understanding the dynamics of change.

Second, since most pollution occurs in metropolitan areas, the urban economics literature identifies the broad underlying trends in metropolitan growth and performance relevant for understanding the impact of changes in air quality. This literature builds on established and now stylized facts in urban economics and also points to areas of controversy especially pertinent to this study. In particular, this literature is useful in understanding the complex interactions between production, consumption and the built environment. More importantly, it forms the basis for a narrative on the direction causality between these interacting forces. The rich literature on urban growth models driven by consumer behavior hints at the limitations of this producer-based study.

A third category attempts to link the broader economic and social effects of air quality to tangible changes in economic performance. Although this is the least developed of all categories it holds the most promise for this analysis. Careful empirical studies will be necessary to ascertain the response of firms and consumers to increases or declines in ozone levels. The methodology exists to understand producer and consumer responses at a specific geographic level but generalizing this across metropolitan areas, specifically those with severe ozone problems, is problematic. This study contributes to this literature and points to some new methodological directions.

Finally, a growing body of literature investigates the EKC at a number of spatial scales to try to determine its relevance in predicting the relationship between levels of pollution and economic development. Given issues of data collection and spatial scale, the efficacy of the EKC in predicting levels of pollution at given levels of income is questionable. Its utility in this context is to provide a theoretical framework to understand the mechanisms that may or may not drive reductions in ozone levels.

2.2 Cost-Benefit Literature

The cost-benefit literature, motivated in large part by the requirements of the Unfunded Mandates Act of 1995 attempts to specifically identify the impact of regulations on the performance of firms or geopolitical entities such as counties, cities or states. The "cost" perspective looks at the effect of environmental regulations on the economy and the "benefit" perspective analyzes the relationship between levels of pollution and metrics of well being such as human health, welfare or wealth. In the former category the common thesis is that in response to regulations, firms or individuals may divert funds intended for investments in productivity or growth-producing enhancements to expenditures for pollution control. Assuming the two types of investment are mutually exclusive (a theory strongly contested by Porter and van der Linde 1995) economic growth and productivity is constrained by the inefficiencies introduced by government intervention in the market.

Regardless of costs, the regulations had the intended effect of improving the quality of the air, a fact that the benefits literature tries to quantify to ascertain the economic value of the benefit. The benefits are estimated by identifying how improved air quality leads to a quantifiable benefit such as reduced sick days, decreased visits to emergency rooms *etc*. For example, Chay and Greenstone (2005) estimate that the improvements in air quality as a result of the CAA meant that 1300 fewer infants died in the U.S. in 1972. Wong *et al.* (2004) use a meta-analysis approach and calculate an impressive list of benefits from the CAA by 2010 including 200 fewer expected cases of postneonatal mortality; 10,000 fewer asthma hospitalizations in children 1-16 years old, 40,000 fewer emergency department visits in children 1-16 years old, 20 million school absences avoided by children 6-11 years old, and 10,000 fewer infants of low birth weight.

The estimations become more controversial when the savings or benefits are interpolated across known or estimated costs associated with each metric because the assumptions necessary to make such calculations are often necessarily heroic. For example, the value of a reduction in 40,000 emergency room visits is calculated to save between 1.3 to 5.8 million dollars. This a fairly straight-forward calculation of public benefit but it takes more assumptions to arrive at the estimate that the reduction of 20 million school absences will save 0.7 to 1.8 billion dollars (1990 U.S. dollars) (Wong *et al.* 2004).

This estimation technique is fraught with difficulties because while most people would agree that they value clean air as a normal economic good (higher income will increase the demand for cleaner air), the non-market valuation of this preference has not been determined. This is because people value services, amenities and benefits available when pollutants are reduced or absent but do not attach a value to the actual absence of pollutants themselves. As an example, citizens may value a reduction in respiratory ailments but not directly attach a value to the reduction in ozone levels that leads to the improvement (McConnell 1997). When the estimations involve putting an economic value on the reduced morbidity, the results become highly controversial. This is because the reduction in morbidity must be multiplied by the value of a human life, known as *VHL—Value of a Human Life* or *VSL—Value of a Statistical Life* in the literature. One estimate of the benefits of the CAA estimated that the benefits of attaining the air quality standards in the South Coast Air Basin in California would save 1600 lives per year at an estimated value of $10 billion per year (Hall *et al.* 1992). While the details are outside the scope of this study the reader is referred to Shogren and Stamland (2002) or Mrozek and Taylor (2002) for a more complete discussion.

Relevant to this study is that in the absence of agreed non-market valuation techniques, calculating benefits is extremely difficult while costs are more easily quantified by identifying expenditures of capital or labor within a firm, state or nation. Other methods to extrapolate benefits such as hedonic house pricing methods and "willingness-to-pay" (or inverse demand) estimates are also used and will be discussed in Chapter 6. When considering the very different methods and scales across which costs and benefits are measured, it is not surprising that the debate on calculating benefits continues unabated.[3]

Numerous studies have examined how air quality regulations affect U.S. manufacturing and economic productivity (Becker and Henderson 2000; Bartik 1998; Duffy-Deno 1992; Gray 1997; Levinson 1996). The existing work generally hypothesizes that the regulations imposed when a county fails to meet an air quality standard (henceforth called "attainment regulations") will negatively affect firm

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[3] The debate became more complicated after 1992 when the Pollution Abatement and Control Expenditures (PACE) Survey was discontinued by the U.S. Bureau of the Census. Due to privacy concerns, data on firm costs is difficult to find and not publicly available. This is in contrast to countries like Finland, where firm financial data is routinely collected.

location, investment decisions, or productivity levels by analyzing how industry-specific regulations affect firm costs and/or productivity. Once a state is determined to fail to meet the ozone standard it is declared in “non-attainment” status. While states have relative freedom in choosing the remedy designed to bring the county back into compliance with the standard (*e.g.,* “into attainment”) the slate of options available are relatively slim and include requiring stricter vehicle emission standards, prohibiting use of certain types of machinery on high-ozone days and requiring firms to reduce emissions. Since the regulatory requirements often extend past firms and onto consumers, a full analysis of the economic impact of air quality standards must also extend beyond the firms and industries directly affected by air pollution regulations.

A wide body of literature exists that estimates the costs of regulations designed to reduce emissions generated by consumers. An estimate for costs of reduction of use or emissions for almost every pollution generating or energy consuming item used by consumers can be found in this literature. The literature ranges from estimates of the costs and benefits of conservation and efficiency policies in the U.S. economy to, to estimating costs to consumers of increased vehicle efficiency standards, to reductions in lawn mower emissions can be found in this literature See Pimentel *et al.* (2004), Kleit (2004) and Gabele (1997) for examples.

There is some evidence that attainment status affects firm location and investment decisions in certain manufacturing industries (see Becker and Henderson (2000) and Becker (1998) for a full discussion). Gray (1997) and Gray and Shadbegian (1993) also find that manufacturing plant location and firm investment decisions are adversely affected by the stringency of air quality regulations at state and local levels. A more recent detailed study of 62 counties in New York State provided strong evidence of this and the authors speculate this is evidence of the gradual diffusion of smog away from concentration in just city centers to a more diffused and more prevalent presence in the suburbs. List *et al.* (2003) coined this phenomenon "spreading of the gray". Others however, find weak or mixed evidence to support the view that environmental regulations affect new plant location, foreign direct investment or regional manufacturing activity (Bartik 1988; Duffy-Deno 1992; List and Co 2000; Levinson 1996). Nevertheless, with the exception of the work by Becker (1998) and Becker and Henderson (2000) and List *et al.* (2003) all of which use county level data, the spatial unit of analysis for the majority of the studies is the local, state, or regional level. Using broader spatial units makes it more difficult to control for other location-specific characteristics that may be correlated with regulatory variables. The county-level cited studies take advantage of a detailed proprietary database, the Longitudinal Research Database (U.S. Census Bureau), which enables researchers to track firm investments and location decisions over time. This provides a rich datasest that is not available in publicly provided data, where firm characteristics are aggregated within the spatial unit *e.g.*, metropolitan area, county, state, or nation.

Besides estimating the effects of regulations on firm activity and location choices, estimating the economic costs of regulations is an equally active area of research. Porter (1991) and Porter and van der Linde (1995) argue that the costs associated with meeting environmental regulations may be outweighed by the innovations in production processes that result when these regulations are put in place. Still, others disagree (Palmer *et al.* 1995) and cite annual expenditures on environmental protection of $100 billion net any estimable offsets. Jaffe and Palmer (1997) use panel data to test Porter's hypothesis and find that lagged compliance costs have a positive effect on research and development (R&D) expenditures.

However, they do not find that increased R&D expenditures translate into innovative output.

2.3 *Urban Form and Economic Growth*

While it is tempting to make explicit connections between location-specific regulations or improvements in air quality and their resulting impact on economic growth, the discussion of the effects of ozone pollution and regulations on the economy is embedded in other socioeconomic trends. Stylized facts about U.S. urban development such as the growth of "edge cities" or suburban sprawl, a general decline in the contribution of the manufacturing sector which has ushered in a new "information age" in U.S. cities, and the migration of population from the "Rustbelt" to the "Sunbelt" are assumed in the discussion. The brief review that follows is for the reader unfamiliar with these trends and summarizes the works most relevant to this analysis but is not intended as a comprehensive review of this expansive body of literature.

Suburbanization is a well-established fact. The structure of U.S. metropolitan areas has changed dramatically over time with population and job growth in suburban areas exceeding that of those in central cities (Nucci and Long 1995; Brennan and Hill 1999; Kahn 2000a; Rappaport 2003; Phelps 2004). Kahn (2000a) states that from 1950-1990 population grew by 92.3% while total land area increased by almost 250%. While there is an established trend towards urbanization (Long and Nucci 1997) not all metropolitan areas are growing. Anecdotal review would speculate cities are dying, but in fact the picture is mixed. It is true people and jobs have moved to the suburbs but not at the rate that might be expected. Brennan and Hill (1999) analyzed job growth in 92 of the largest cities in the U.S. between 1993 and 1996 and found that only 25% of the central cities had job growth that was stagnant or declining relative to their suburbs. In 17 of the 92 cities job growth rate in the central city outpaced that of the suburbs.

What is still a matter of debate is the impact of suburbanization on metropolitan economies. Some argue that improved information technology and lower transportation costs deprive the city of its historic role as the center of agglomeration economies, and hence, the city will decline. Yet Glaeser (1998 and 2000a) describes the changing premium of cities (proxied by land rents) as a function of two additive characteristics, the productivity premium from density (productivity premium). and the effect of cities on quality of life (urban amenity premium). Most work on agglomeration externalities has in large part been based on a manufacturing based economy (Henderson 1988; Sveikauskas 1975), but it is clear that while the information age may change the primary actors, the "spatial concentration of economic actors increases productivity at the firm level by increasing the flow of new ideas" (Glaeser 2000a, 7). The function of other cities changed from a primary role of meeting the needs of producers to meeting the requirements of a new class of consumers. As workers become more mobile, the city quality of life becomes a factor in continuing to attract high levels of human capital, an acknowledged determinant of city productivity growth. Glaeser (2000a) finds that demand for urban amenities (or a high quality of life) is rising. The quality of life, or amenity index, calculated by the author indicates the highest amenity cities are all in California, except for Honolulu, and the low amenity cities are Anchorage, Alaska and Trenton, New Jersey. The conclusions leave no doubt that even with suburbanization, areas with either abundant land resources and natural or built amenities will continue to offset the advantages of density as typically described in the manufacturing age[4] (Glaeser 2001).

[4] The exact definitions of metropolitan and suburban areas will be discussed further in detail in Chapter 3. For now urban, city and metropolitan are used interchangeably.

How does suburbanization and the quest for a higher quality of life affect the environment? Kahn (2000a) finds that suburban households live in twice the land area as their urban counterparts and drive 35% more. An increase in air pollution might also be expected but is not observed. Kahn hypothesizes that air quality remained satisfactory because emissions per mile driven due to technological innovations fell faster than vehicle miles traveled increased. The author acknowledges that the results were based on 1995 data and the conclusions may not hold in the future. There are two reasons this might not be the case. First, decreasing returns to technological innovation in the auto industry mean reductions in emissions are declining and the increased popularity of SUVs (considered a small truck and until very recently subject to less stringent regulations) in the less dense suburban areas will likely lead to an increase in emissions per mile. Nevertheless, increases in fuel efficiency continue to drive an increase in vehicle travel. Known as the rebound effect, Small and Van Dender (2006) estimate average increases in fuel efficiency leads to short-term increase in miles traveled of about 3-4% and long-term increases of 12-15%, depending upon assumption of fuel prices and other endogenous variables.

The general shift of the population from the Rust Belt to the Sun Belt has important implications for the study of ozone. As a photochemical oxidant, ozone problems are most prevalent in sunny areas. Rappaport (2003) uses decomposition analysis to show the geographic component of urban growth from 1950-2000. He confirms the general shift in population from the Northeast and Midwest to the South and West and shows that urban areas that experienced continual population decline were located in the Northeast and Midwest and those that grew continuously over the time period were located in the South and West.

An analysis of clustering of industries is inextricably linked with the discussion of ozone regulations because it sheds further light on the interdependencies between economic activity and the bi-product of that activity. With manufacturing, the connection is more obvious as point-source emissions are identified and controlled. However, the connection is not as explicit in a more service-oriented economy where many of the externalities of this activity are non-point source (*e.g.*, motor vehicle emissions) and therefore harder to identify and control. In addition to exploring sectoral clustering tendencies, I present partial correlations to dissect the changing relationship between producers in the service sectors, population and the perceived demand for density. The nature of this relationship will arguably shape the future of U.S. metropolitan areas (Glaeser 2000).

Beginning with Marshall (1890) the notion of agglomeration and externalities has been typically associated with cities and industrial areas where the proximity to other firms and a common labor pool formed the foundation for cost or technological benefits. Urban form and the economic geography of production of goods and services has changed dramatically and so too has the nature of externalities. Many firms, able to now leverage advanced communications technology, no longer require immediate proximity to customers, employees or other firms. This new freedom increases mobility and allows firms to locate so as to minimize tax burdens and labor costs which often means locating outside traditional urban areas into less densely populated towns and small cities. There are many terms for these new economic entities, which until recently existed outside traditional urban economics, including the "economic geography of the banal" (Phelps 2004) or "edge cities" (Garreau 1991) or, most recently, "micropolitan areas" as defined by the U.S. Bureau of the Census (2005). These types of urbanized areas will continue to play an increasingly prominent role in the economic landscape of the U.S.

It is worthwhile to distinguish between two different types of externalities which can broadly be classified by the purported benefits of agglomeration, pecuniary and technological. These two broad categories are not mutually exclusive. Pecuniary benefits refer to the cost benefits of agglomeration which may accrue to firms by virtue of locating in close proximity to each other. Pecuniary benefits can be further segmented by the type of cost savings involved: through establishment of a local pool of labor (Marshall 1890), reduced inter-firm transaction and shipment costs because of minimal distances between firms (Porter 1998) and cost reductions achieved through the use of shared infrastructure and collective resources. Examples of technological externalities are the classic industrial agglomeration (Marshall 1890) and more recent research tries to identify the "knowledge spillovers" that accrues to localized industries from collaborating with their neighboring firms (Krugman 1991; Porter 1990). The hypothesis is that the dynamics of locally interacting related firms creates dynamism and flexibility but also learning and innovation (Malberg and Maskell 2001).

However, as discussed earlier, today's expansive and changing urban form means agglomeration cannot be viewed strictly in Marshallian or neo-Marshallian terms. The new economic geography and the rise of "intermediate" locations present problems for economic geographers in trying to understand external economies. Martin (1999) finds the new pecuniary externalities may operate over very broad geographical areas so that being located on the periphery will no longer hinder access to markets or pecuniary externalities (Phelps 2004). Phelps (2004) puts it succinctly when he writes:

> If it is technological externalities that continue to act as significant centripetal forces drawing activity to relatively localized urban industrial agglomerations, and if it is now the generally widely available pecuniary externalities that tend to act as centrifugal forces permitting their dissolution, it is the relationship between pecuniary and technological externalities which is of importance for

> understanding today's spatially diffuse, service-sector agglomerations (p. 980).

2.4 Air Pollution, Economic Performance and Metropolitan Characteristics

The cost-benefit literature goes only part way in explaining the complex relationship between pollution, regulations and economic performance. Once pollution is reduced, either through investments in pollution control, relocation of industry or other systemic changes, what are the overall economic effects of the resultant clean air? This is a smaller body of literature for many reasons, and is distinct from the "benefits" literature described above because it does not rely on non-market valuation but rather on hedonic pricing methods of estimates of revealed preference or "willingness-to-pay" for pollution reduction. While there is overlap between these groups, for the purposes of this analysis the distinguishing factor is the direct monetization of a reduction in air pollution as revealed in housing price or economic performance rather than calculated estimates of aggregate value as accrued to the collective (as in the examples in the previous section).

Kahn (2000) finds evidence that reduced ozone levels (due primarily to heavy regulation) in formerly-polluted Los Angeles suburbs contributed to a period of accelerated growth compared to their own previous growth patterns and a group of control counties. Another study (Kahn 1999) revealed that the former manufacturing area of the Midwest, commonly referred to as the "Rust Belt," experienced economic renewal as a result of air quality improvements. Kahn uses valuation techniques to estimate possible future economic gains in housing prices. However, Kahn acknowledges that the flight of manufacturing would limit economic opportunity for current home owners. Thus, "(t)he likely winners from the reduced manufacturing activity would be footloose service firms and retired renters seeking local higher quality of life" (Kahn 1999, 373).

Using a different data set for the Los Angeles Basin Kahn (2001b) showed that declining ozone levels, holding all other housing amenities constant, had a positive effect on housing prices. Chay and Greenstone (2005) found that overall, the improvements in air quality induced by the TSP (Total Suspended Particulates) standards were associated with a $45 billion aggregate increase in housing values in non-attainment counties between 1970 and 1980. In both cases, the pollutant analyzed would have been tangible and visible to the naked eye. Particulates are small particles of matter that may or may not be visible to the naked eye in low concentrations but in high concentrations are visible and, together with ozone, form what is known generically as smog. In the case of the Kahn (2001) study many of the counties in the study were classified as 'Extreme' meaning that concentrations of ozone were a serious threat to human health. This would have manifested itself as a serious smog problem, for which LA is well-known. It is likely, if not certain, that citizens actually perceived the ill effects of ozone, either as the recipients of extensive government and non-governmental education campaigns that detailed the harmful side effects of exposure to ozone and/or through physically experiencing ill effects of ozone, either through visualizing smog or experiencing respiratory difficulties, or both.

The study by Kahn (2000) discussed in the introduction was important because it was the first to conclusively link reductions in ozone levels to economic effects. A further study (Kahn 2001), shows that while areas with high levels of ozone featured lower rents, the market valuation is much lower than other typical indicators of urban amenities, such as human-capital. For example, in 1990 a 10% increase in the number of college graduates resulted in an 8.2% increase in rents. By contrast, an extra 10 days in which a county exceeded the ozone standard lowered rents in 1990 by only 0.9%. While these studies provide evidence of reactions to ozone in a place, it would be heroic to generalize these findings to the regional or national level. In spite of this drawback, hedonic pricing methods are the most effective means to quantify links between regulations or environmental quality and specific economic attributes such as changes in property values or health care costs. In other words, hedonic pricing methods clearly translate the physical impacts of pollution to a welfare impact (Anderson and Crocker 1971; Carpenter *et al.* 1997; Kahn 2000; Masemore *et al.* 1997 and Oak Ridge National Laboratory 2002). As the methodology for measuring hedonic price impact continues to improve we can expect a more sophisticated understanding of the overall welfare benefits from changes in air quality.

2.5 The Environmental Kuznets Curve

It is difficult to discuss the relationship between economic performance and pollution levels without acknowledging the prevalence of studies of the Environmental Kuznets Curve (EKC) in the literature. Recall that the EKC is hypothesized to be a U-shaped curve when plotting income on the horizontal axis against levels of pollution (or emissions) on the vertical axis (as shown in Figure 1.1). Reduced form regression models in EKC studies typically regress cross-country levels of emissions or ambient pollution measures on polynomial specifications of income per capita (Shafik and Bandyopadhyay 1992; Selden and Song 1994; Dinda 2004; Rupasingha 2004). In essence, the theory underlying the EKC suggests that environmental degradation is a natural consequence of economic growth, emphasizing that pollution will get worse and then improve as incomes rise. While the regressions cannot explain the mechanism by which the relationship changes over time, there are various hypotheses discussed in the literature and can be summarized as follows: first, is that environmental quality is a normal good such that more will be demanded at higher incomes; second, technological progress leads to a more efficient use of resources thereby reducting pollution; and third that political openness and education lead to increased demand for a higher quality environment (Bruvoll and Medin 2003).

Structural characteristics undoubtedly affect the income and environment relationship and the relevance of these factors in previous studies reminds us that the process by which an EKC relationship is developed is not automatic and that a rise in income will not necessarily translate into a better environment. However, political openness, education and technological change rarely improve in the absence of economic development so the driving mechanism is most likely economic growth together with technological progress.

Cross-country studies provide evidence that at a certain level of per capita GDP and technological development, demand for environmental quality rises together with the capacity to control pollution. Evidence of an EKC has been found in a number of studies and for a broad variety of constituent pollutants including Total Suspended Particles (TSP) and Sulfur Dioxide (SO_2) (Shafik 1994; Grossman and Krueger 1994). The results for Carbon Dioxide are mixed and it is hypothesized that the physical and chemical properties of CO_2 make it unlikely to be perceived as a problem at local levels (see Moomaw and Unruh (1997) for a full discussion). Estimates show an Income Turning Point (ITP) for average annual personal income for this inverse U-Shaped curve to be between approximately $10,000 and $13,000 (Dinda *et al.* 2000). Should this theory hold, the U.S., with average per capita income in 1997 (chained 1992 dollars) of $17,500, should be close to eradicating environmental pollution.

Estimating an EKC on a smaller geographic scale, say for a single country or region, becomes a more complex exercise. Not only are the problems in estimating environmental quality magnified, spatial correlation effects become more pronounced as the units of analysis become more compact. The U.S. enjoys modest homogeneity in pollution levels across its major metropolitan areas relative to the extreme heterogeneity found in cross-country regressions. In combination with difficulties inherent in monitoring and modeling air quality data, it is questionable whether it is useful to replicate an EKC for U.S. counties. The EKC has never been successfully estimated for the U.S. and there is preliminary evidence that there is not enough heterogeneity amongst the pollution and income scales to identify the relationship (Grossman and Krueger 1993; McConnell 1993; Carson *et al.* 1997). Grossman and Krueger (1993) note that ozone was the only pollutant which failed to show a definitive time trend during the1979-1988 study period. Rupasingha *et al.* (2004) use a more heterogeneous dataset, the Toxic Release Inventory (TRI), which captures toxic waste releases to air, land and water. The study controls for spatial effects and addresses the issue of *scale mismatch* where the underlying spatial sampling design has little connection to the framework used to collect economic data (Anselin 2001).[5] This advanced technique yields results consistent with an EKC relationship between toxic waste and per capita income.

Most relevant to the present study, Emerson and Pendleton (2004) recognize the lack of a theoretical framework for the presence of the EKC and propose a utility model that hypothesizes that the income-pollution relationship depends on the level of disamenity of the pollution. In other words, the sensitivity of the relationship between income and pollution will depend on how noxious citizens find the pollutant. The authors find strong evidence that the ITP (Income Turning Point) decreases as the level of toxicity increases. The disamenity factor is strongly linked to the level of toxicity.

A complete analysis of the EKC is outside the scope of this study but it is relevant to the present discussion for the following reason: if the prevalence of most pollutants declines with income (and by extension, economic development), but after a certain level, the prevalence of ozone does not decline with income, then is it possible

[5] This issues of scale mismatch and spatial issues will be discussed in more detail in Chapter 4.

that at the upper end of the EKC, representing the highest level of development, the level of ozone is invariant with income? If the income and pollution relationship does depend on the extent to which the pollutant is perceived as a disamenity then at low to moderate levels of ozone the EKC does not predict the relationship. In short, in advanced economies it is plausible that ozone is the one pollutant, that by virtue of its physical and chemical properties and diffuse spatial and temporal effects that will defy the theory that pollution is a disamenity and will persist at harmful levels with economic growth.

CHAPTER 3

DESCRIPTION AND CATEGORIZATION OF DATA

3.1 Introduction

The sources of the data are described below and a description of the taxonomies used to categorize the data follow. In the majority of the study the unit of analysis is the county, the smallest spatial unit for which both socioeconomic and regulatory data and some classes of air quality data is uniformly available. The study primarily focuses on counties that are defined as metropolitan by the U.S. Census although non-metropolitan counties are used as a basis for comparison. In cases where using county-level data is not feasible, metropolitan level data is used.

3.2 Economic and Environmental Performance Measures

3.2.1 Population, Wages, Income and Density Measures

The economic data set initially entailed all 3,118 counties that comprise the contiguous United States, however some counties were dropped due to data constraints, leaving a total of 3098 counties. The source for the most of the data used is the REIS (Regional Economic Information System) of the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce. The REIS includes annual data on personal income, population, and earnings for every two-digit industry for all counties in the nation. [REIS has the most comprehensive measures of earnings and employment available for metropolitan areas.] The wage measure described below is the average annual metropolitan wage calculated from total earnings and total employment. The earnings data include proprietors' income as well as all wages, salaries and bonuses. One advantage of using the REIS employment data is that it includes the self-employed as well as all employees. Unlike the case with the Census' *County Business Patterns*, which excludes the self-employed, all government and railroad workers, and the Bureau of Labor Statistics' *Employment and Earnings:*

States and Areas (Bureau of Labor Statistics) which excludes the self-employed and agriculture workers. These exclusions are not trivial. For 1996, U.S. employment reported by *County Business Patterns* was 102 million while the BLS total was 120 million. The REIS total, the source used in this study, was 152 million. Although the data derived from REIS is annual, this data set is quinquennial, 1977 to 1997, in order to make it congruent with the CBP dataset.

REIS also provides data for Per Capita Personal Income (*PCPI*) at the county level.[6] *PCPI* (in 1996 chained dollars) which is a population-weighted average of total county earnings and non-wage income. It serves as a useful proxy for the overall performance of a county's economy because it captures all wage and non-wage income, which could be in the form of interest, dividends, or pensions. In other words, PCPI captures income that is not location specific. The county population data is drawn from two sources: *REIS* and the *City and County Data Book* (U.S. Census Bureau). The two sources are required because each source uses a different definition for independent cities, a phenomenon almost entirely confined to the state of Virginia. Total number of establishments is provided by the *County Business Patterns* (Bureau of Economic Analysis, U.S. Census Bureau). Information on a county's land area is provided by *ESRI.* The variable Manufacturing Density *MFGDENS* was created by dividing the number of manufacturing establishments in a county by the number of square miles in that county in 1990.

Each sector's share of economic activity was calculated by dividing REIS estimates of county earnings in that sector by total county earnings consistent with the sectoral taxonomy described below. As noted, the shares of manufacturing, distribution, advanced consumer services, and producer services capture just over 50 percent of county economic activity and since they represent the *traded* goods and

[6] Estimates for some counties in Alabama were not available.

services, they arguably represent the sectors that at least partially drive the development of the economy. While it is unlikely that ozone regulations will have a direct impact on the service sectors, it is possible secondary effects of regulations will be observed as the structure of the national economy shifts away from manufacturing.

3.2.2 Emissions and Attainment Data

Emissions data come from the U.S. EPA AIR database. Emissions are the quantity of pollutants released into the air during a year and are normally estimated from amounts of material consumed or product produced and are provided to EPA by state environmental agencies. Some estimates are for individual sources, such as factories, and some estimates are county totals for classes of sources, such as vehicles. Emissions data is available for select years from 1990.

To understand the attainment data used in the study a more complete discussion of the regulatory environment is necessary. As mandated by Congress in the Clean Air Act (CAA, Section 109(a)(1)), the Environmental Protection Agency established National Ambient Air Quality Standards (NAAQS) to achieve and maintain a certain level of air quality throughout the United States. One of the six criteria pollutants for which the NAAQS has been set is ozone, a photochemical oxidant that is a major component of smog. Ozone results from complex chemical reactions between volatile organic compounds *VOCs* and nitrogen oxides *NOx* in the presence of sunlight and is known to cause a number of health problems associated with respiratory function.

The standard for ozone specifies a maximum concentration above which there may be adverse effects on human health. Until 1997 the threshold value for ozone was set at 0.12 parts per million (ppm), measured as a 1-hour average concentration. An area met the standard if the highest hourly value did not exceed this 0.12 ppm threshold more than one day a year. The standard is presently 0.08 ppm measured as an 8-hour average concentration. If an area does not meet the designated standard, it may be designated a non-attainment area through a formal rule-making process. An area is considered in attainment if it meets the ozone air quality standard for three consecutive years.

If a State contains a non-attainment area, it is required to submit a State Implementation Plan (SIP) that describes how and when the area will be brought into attainment (CAA, Section 172(c)(1)). SIPs must also describe how states plan to make reasonable progress towards attainment by limiting the emissions of both *VOCs* and *NOx* (CAA, Section 172(c)(2)). In other words, States must show their non-attainment areas are working towards compliance with the standard before they approach their deadlines.

The ozone non-attainment area classifications as they appear in the Clean Air Act Amendments of 1990 (Section 181(a)) are detailed in Table 3.1.

Table 3.1 Ozone Non-attainment classifications

Classification	***Description***
Extreme	area with a design value of 0.280 ppm and above
Severe 17	area with a design value of 0.190 up to 0.280 ppm and has 17 years to attain the standard (from the year 1990, when the Clean Air Act Amendments were enacted)
Severe 15	area with a design value of 0.180 up to 0.190 ppm and has 15 years to attain the standard (from the year 1990)
Serious	area with a design value of 0.160 up to 0.180 ppm
Moderate	area with a design value of 0.138 up to 0.160 ppm
Marginal	area with a design value of 0.121 up to 0.138 ppm
Section 185(a)	area designated non-attainment as of the enactment date of the CAA Amendments of 1990, but has not violated the ozone NAAQS during the 36 month period immediately prior; or those areas without sufficient data to determine whether or not it is meeting the ozone standard

Figure 3.1 shows those counties that failed to meet the 1-hour ozone standard in 1977, 1987 and 1997. In 1977, 682 counties failed to meet the ozone standard and by 1997 there were only 296 counties that failed to attain the ozone standard. The counties that failed to meet the standard for all three years are denoted by a "1" and discussed as *"non-attainment"* counties. Those counties that met the standard at least one year are denoted by a "0" and referred to as "*in attainment.*" The attainment counties took necessary action to curb emissions sufficiently to attain the ozone standard but also represents a general improvement in air quality over the two decades. The attainment designation serves a dual purpose as it represents the presence of regulatory mechanisms but also serves as a crude proxy for air quality in a region. Given difficulties in determining ambient air quality (discussed further in Chapter 4), the attainment variable becomes a convenient tool for researchers by providing a county-level snapshot of air quality for every year the designation is made.

Air quality non-attainment regulations are the appropriate regulatory mechanism to test overall effects because they are *location-specific* rather than *firm* or *industry-specifi*c. Regulatory controls within non-attainment mechanism may affect a number of actors and activities and States are free to remedy a non-attainment area in the most efficient way. This makes it difficult to ascertain the true effect of the regulation since there is not a uniform sanction that can be specifically tested for adverse affects. However, the non-attainment regulations are applied uniformly across counties that fail to attain the ozone standard so there is complete spatial congruence when paired with county-level economic data. Thus, the attainment standards make it possible to reposition the analysis from the firm level to the county level while still capturing, although admittedly more indirectly, the effect of regulation on firms.

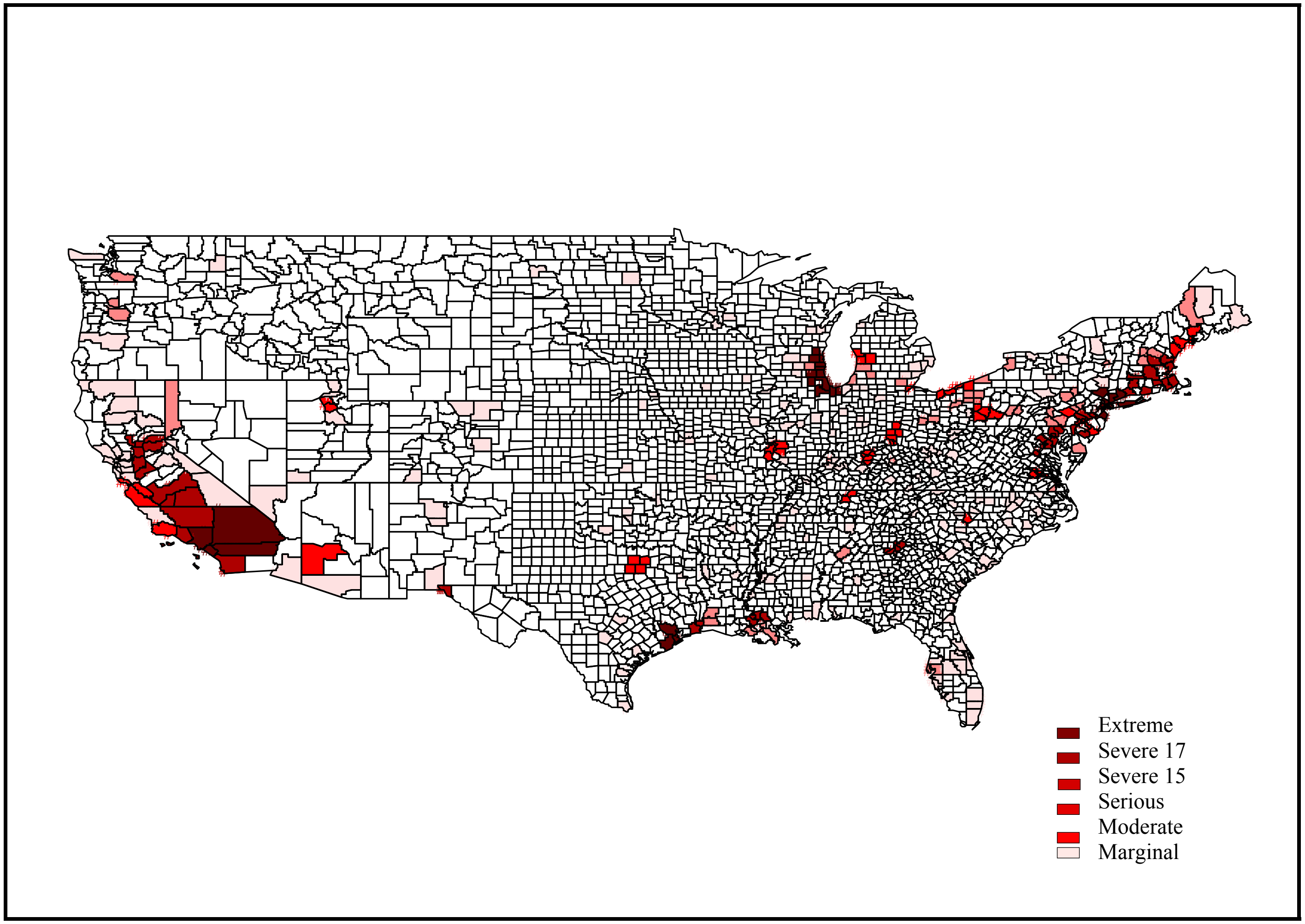


Figure 3.1 Ozone Non-attainment areas in 1997

If a state contains a non-attainment area, it is required to submit a State Implementation Plan (SIP) that describes how and when the area will be brought into attainment (CAA, Section 172(c)(1)). SIPs must also describe how states plan to make reasonable progress towards attainment by limiting the emissions of both VOCs and NOx (CAA, Section 172(c)(2)). In other words, states must show their non-attainment areas are working towards compliance with the standard before they approach their deadlines.

Depending on whether stationary pollution sources are new or existing, they face different requirements when located in non-attainment areas. Once an area is designated as non-attainment, existing sources located there must adopt "reasonably available control technologies" (RACT) as expeditiously as practicable. Requirements for existing sources are not as stringent as they are for new stationary sources that plan to locate in non-attainment areas or existing sources that plan to make significant modifications.

New major stationary sources locating in non-attainment areas and existing sources seeking to make major modifications must obtain pre-construction permits and undergo New Source Review (NSR). To obtain a construction permit, these sources must demonstrate that they will not negatively impact a non-attainment area's ability to attain the ozone standard by its target date by purchasing VOC or NOx offsets. Offsets are allowable reductions from other sources within the non-attainment area that completely eliminate any potential increase in emissions from the new or modified source. Depending upon the severity of non-attainment, the source may be required to obtain a greater than one-for-one offset for its emissions.

New and modified sources must also demonstrate the ability to achieve the "lowest achievable emissions rate" (LAER). LAER is the most stringent emissions limitation in a SIP, or alternatively is the most stringent level of pollution control achievable in the related industry group. In attainment areas, new sources are subject to Prevention of Significant Deterioration (PSD) regulations (CAA, Section 161). PSD regulations require new sources to adopt the best available control technology (BACT), a lower standard than LAER, and to obtain pre-construction permits. In general, new sources in non-attainment areas are subject to stricter requirements regarding air pollution control than new sources in attainment areas.

The more an area is out of compliance, the stricter are the requirements on the sources in that area. For example, the definition of “major source” (*i.e.*, a source required to comply with the NSR regulations) differs across ozone non-attainment areas based on their classification. A larger number of sources are included in the definition of new source as the classification of the area is worse. This requires a larger proportion of sources in an area to take action to limit emissions of the ozone precursors VOCs and NOx.[7]

The number of mandates on non-attainment areas and their stringency also differs based on classification (CAA, Section 182). For example, existing sources in *marginal* non-attainment areas only have to ensure they are meeting RACT requirements for VOCs and new sources must go through New Source Review. Sources in *moderate* non-attainment areas must comply with the above, but must also meet additional requirements including the adoption of RACT to control NOx emissions. Sources in *serious* non-attainment areas must go several steps further by formulating a plan for 3 percent annual average reductions in ozone precursors until the area is considered in attainment, modeling a demonstration of attainment of the

[7] Any source that has the potential to emit the following amounts of VOCs or NOx combined is considered major: greater than 10 tons per year (tpy) in extreme non-attainment areas, greater than 25 tpy in severe non-attainment areas, greater than 50 tpy in serious non-attainment areas; and greater than 100 tpy in marginal or moderate non-attainment areas.

standard, adopting a clean fuels program (if applicable), and adopting an enhanced monitoring plan among other requirements.

3.2.3 Housing Data

Six variables represent composition of housing and area demographics for the regression analysis in Chapter 7. The first, *POPGR* is calculated by dividing the population in 1997 by the population in 1987 providing a 10-year perspective on population change in each county. The other five variables are derived from the 1990 Census of Housing available from the U.S. Census Bureau. The variable *MEDVAL* is taken directly from the census and is the calculated median sales price of residential houses in a given county. The variable *MINORITY* is calculated by dividing the total population of non-white residents in a county by the total population. *WORKAGE* is the proportion of the population who were between the ages of 30 and 49 in 1990, arguably the stage in which people have increasing purchasing power. This variable is most likely to capture the sector of the work force in their prime earning years and may be likely to prioritize high paying jobs over other considerations. Likewise, *RETIREAGE* is the proportion of the population that is above the age of 65 and may be more likely to seek amenities and warm weather. *OWNER* is the proportion of owner-occupied homes. Finally *DETACHED* is the proportion of the housing stock which is detached single unit houses.

3.2.4 Geographic and Amenity Data

To control for regional trends in these economic measures the U.S. is divided into four main regions: Midwest, South, Northeast, and West. This partition is used to create dummy variables for the econometric section of Chapter 6. Following Glaeser (1992) the West is set as the base variable against which the other three regions can be compared.

The U.S. Department of Agriculture (USDA) calculated an *Amenity Scale* by combining six measures of climate, typography and water area that reflects the qualities most people prefer. The measures are warm winters, winter sun, temperate summer, low summer humidity, topographic variation and water area. This is denoted in the study as *AMEN* and each county is given one of the following rankings as shown in Table 3.2 based on deviations from the mean level of desirability of natural attributes:

Table 3.2 Rankings for Amenity Scale for U.S. counties

Deviations from the mean
1 = Over -2 (Low)
2 = -1 to -2
3 = 0 to -1
4 = 0 to 1
5 = 1 to 2
6 = 2 to 3
7 = Over 3 (High)

A map of the *AMEN* values in Figure 3.2 reveals what is now a stylized fact, that the Midwestern states are not highly valued for their natural amenities while the coastal areas are considered highly desirable.

The climactic variables that represent average summer *(SUMMER)* and winter temperature *(WINTER)* and hours of sunlight *SUN* from 1941 – 1970 are also used. *WATER* is a measure of the total area of shoreline in a county and *TYPO* represents the typography of the landscape as ranked by the USDA based on known preferences. This data is from the Area Resource File (ARF) maintained by the Office of Research and Planning for Health Professions with the Health Resources and Services Administration.

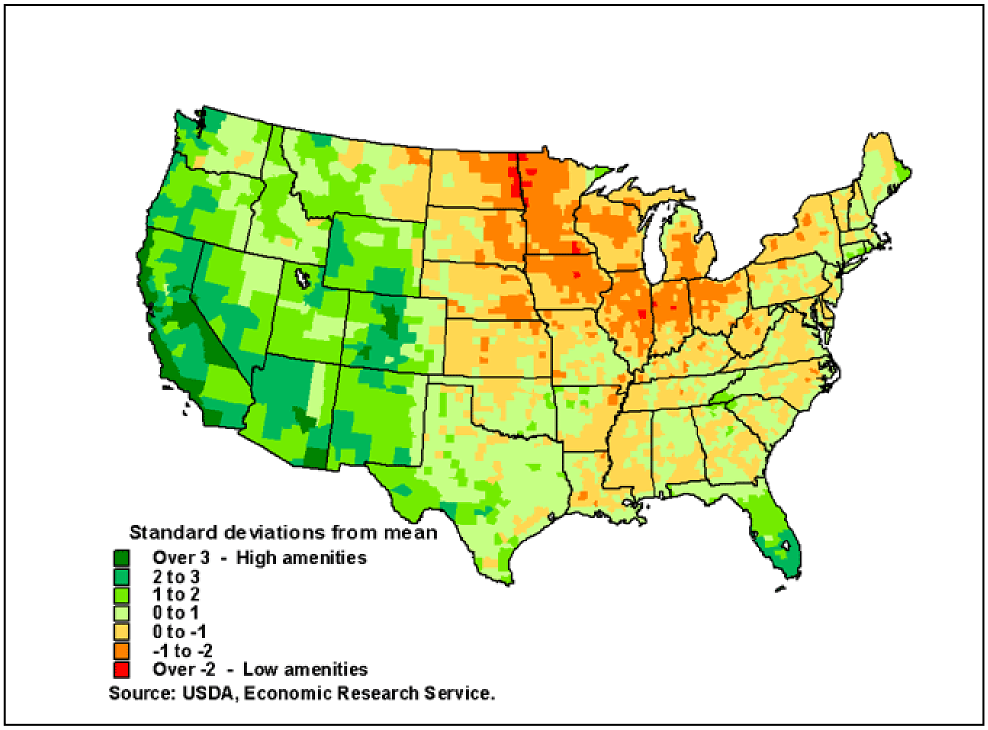


Figure 3.2 Map of Natural Amenities Scale

3.3 Taxonomies

3.3.1 Dynamic Spatial Taxonomy: Metropolitan and Non Metropolitan Counties

Metropolitan boundaries shift and new metropolitan areas are recognized over time making metropolitan definitions dynamic rather than static. Long and Nucci (1995) show that since counties that comprise a metropolitan area may, and do, change over time metropolitan population growth is primarily a result of annexation of counties rather than demographic shifts towards urban areas. In addition, Long and Nucci explicitly argue that treating metropolitan definitions as static by assigning counties metropolitan status based on current definitions is highly problematic. For example, using a static definition of metropolitan status, counties that became metropolitan in the 1990s are treated the same as counties that became metropolitan in the 1960s.

The shifting boundaries of metropolitan territory raise questions whether metropolitan population shifts (and the changes to the economic landscape of an area that accompanies such shifts) are due to classification changes and/or "real" changes along this dimension (Long and Nucci 1995). This chapter introduces a more advanced control for the changing metropolitan boundaries by classifying counties into long term metropolitan and non-metropolitan counties and transition counties, a combination of additions to long term metropolitan areas (*i.e.* "fringe"), and counties of newly recognized metropolitan areas, introduced by Long and Nucci (1995).

The import of this taxonomy is made explicit by the fact that 98 counties that moved from non-metropolitan to metropolitan status in 1994 or later. Failure to use an appropriately dynamic spatial taxonomy would designate these counties as metropolitan for the entire study period, thereby biasing the results.

Statistical consistency is not the only reason to track MSA definition. This distinction is also important because the known characteristics of metropolitan areas are endogenous to this study. First, metropolitan areas benefit from agglomeration externalities and knowledge spillovers (Becker *et al.* 1999) that create distinctively different economic conditions (Sveikauskas 1975; Glaeser *et al.* 1995). Second, to the extent that metropolitan status is a result of increased investment by the private sector, expanding infrastructure, and/or increased road travel, a metropolitan distinction is an indication of the increased prevalence of conditions that make attaining the ozone standard more difficult.

Six official metropolitan classifications, developed after the 1960-1990 decennial censuses, become the source of county metropolitan classification information. Counties which were part of 1963 metropolitan areas form category A. Counties added to these areas as their boundaries expand and newly recognized areas and their additions become a transition category, Category F. The 3,097 counties in the continental United States are partitioned into the six sub-populations, designated according to when these counties were designated as *metropolitan* are defined in Table 3.3.

Table 3.3 Description of Metropolitan Taxonomy

County Category	Description
A Counties:	counties first designated as metropolitan during the 1960s and that have remained so up to 1997.
B Counties:	the 105 counties designated as metropolitan during the 1970s and that remained so up to 1997.
C Counties:	the 255 counties designated as metropolitan during the 1980s and that remained so up to 1997.
D Counties	the 107 counties designated as metropolitan during the 1990s and that remained so up to 1997.
E Counties:	the 2207 counties (71% of all continental counties) which throughout the period 1963 to 1997 were designated as non metropolitan.
F Counties:	the 75 counties which shifted from a metropolitan to a non metropolitan designation at some point during the period 1963 to 1997 and which then remained non metropolitan up to 1997.

Figure 3.3 is a map of the spatial representation of the metropolitan categories of the taxonomy with all counties comprising metropolitan areas in 1997.

3.3.2 Sectoral Taxonomy

A taxonomy of economic sectors is used to develop variables representing the proportion of sectoral wage shares for each county. Traditionally, industry groups are divided into primary (agriculture, forestry, fisheries, and mining), secondary (manufacturing and construction), and tertiary (distribution and services) categories, but borrowing from international trade theory (Krugman 1980) distinguishes between *traded* and *non-traded* goods and services. Henderson (1988) extended this notion to regional or metropolitan economies and showed that 50 to 60 percent of metropolitan output falls into the traded category for U.S. metropolitan areas.

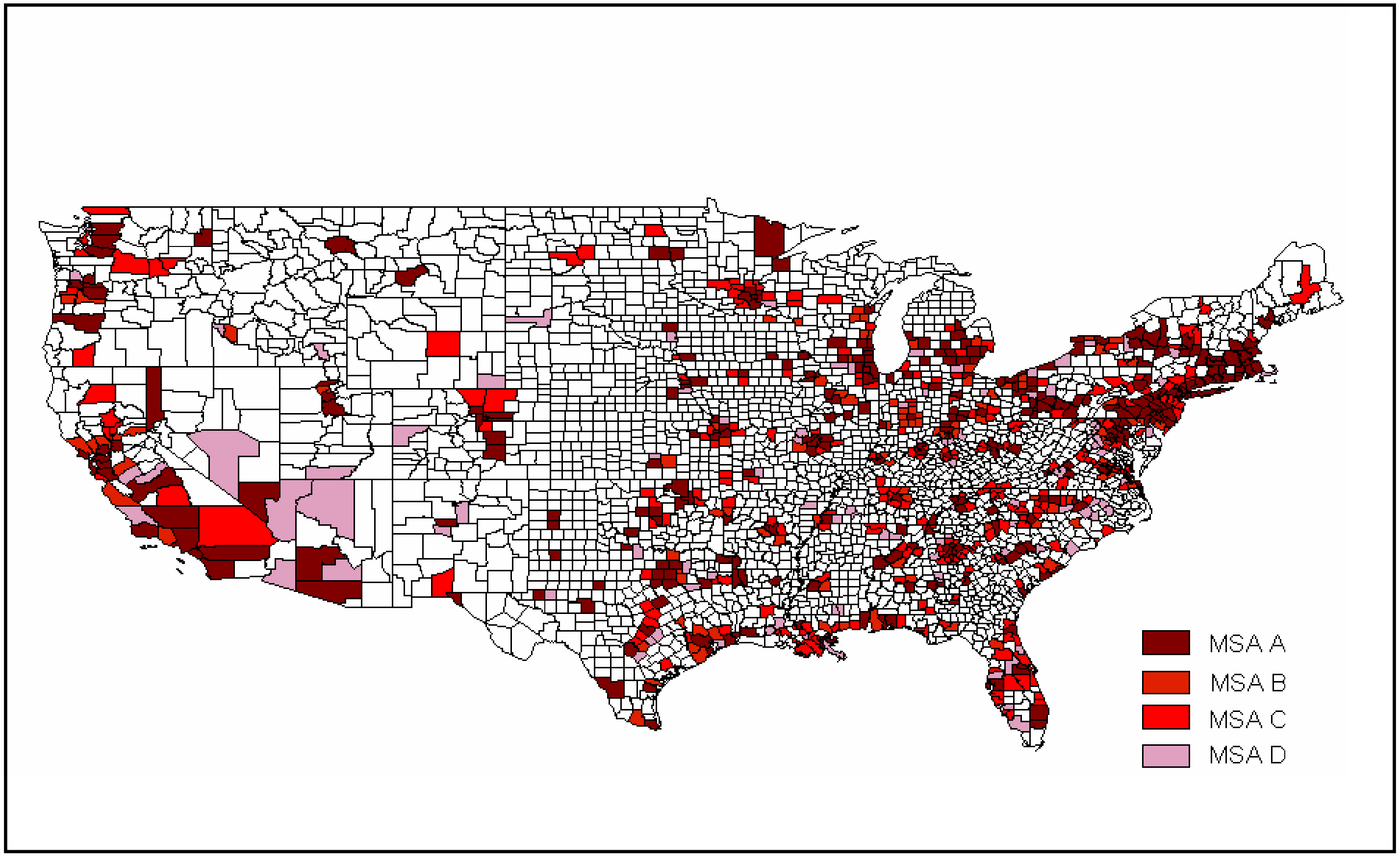


Figure 3.3 Metropolitan Taxonomy in 1997

In the simplest sense, metropolitan areas are an aggregation of adjacent counties or a single county that meets the criteria of a metropolitan area. As the building blocks of metropolitan areas, county economies can also be partitioned according to the *traded* and *non-traded* dichotomy.

Traded goods and services can be exports or imports of a metropolitan economy, while non-traded goods and services are normally produced and consumed locally. Non-traded goods and services are not subject to competition from outside the metropolitan area. Examples of tradable goods and services include the manufacture of textiles, automobiles, computers, air transportation, and banking and legal services. Non-traded goods and services include construction, electric and gas utilities, retail trade, personal and social services, and government and local passenger transportation. Tradable goods and services tend to drive economies while non-traded goods and services are those that support the population and the trading sectors.

Following Drennan (1999) and Drennan *et al.* (2002), wage shares from the "traded" side of the economy are calculated. Shares from *Distribution DIST,* and *Manufacturing MFG* sectors, as well as a broad class of service sectors referred to as Information Services (see Appendix A for a list of SIC codes within each category) form the basis of the analysis. Information Services are broken down into producer and consumer services and includes *Financial Producer Services PSFIN* (banking, securities, insurance, and real estate), *Other Producer Services PSOTH* (communication, business, professional and legal services), and *Advanced Consumer Services ACS* (health services, entertainment, and educational services).

The five traded goods and services sectors sum to 56% of metropolitan earnings on average, so using this taxonomy excludes almost half of the economy. Yet the entire economy is included in the average wage measure because it can be argued that the traded goods and services sectors drive the metropolitan wide wage level. Glaeser *et al.* (1992) and Henderson *et al.* (1995) use industry employment as the basis for measuring specialization but earnings may better reflect the importance of an industry for a metropolitan area. Employment shares measure industry mix well, but they are not representative of the impact on the local economy. For example, both the securities industry (SIC code 62) and the health services industry (SIC 80) accounted for 8% of private employment in Manhattan in 1996. But the securities industry accounted for 24% of private earnings in Manhattan, while the health services industry accounted for less than 6% (U.S. Department of Commerce 1998). Using earnings shares rather than employment shares is also an advantage because it captures differences in the quality of labor while employment shares simply capture the relative weight of a sector treating the sector's labor as homogeneous.

The decision to include only the traded sector of the economy in this study was based on the assumption that goods and services that are not created specifically for consumption within a specific geographic area are the primary engines of economic growth. This paradigm is clearly changing as consumers play a more important role in shaping the economic fabric of an area. The burgeoning service sector such as coffee houses, retail trade, restaurants, some IT and computer services and purveyors of art and culture, exist solely to meet the needs of an ever-demanding population of consumers. The output of many the class of service establishments not included in this study is often purchased and consumed as they are produced and are therefore not considered "tradable." Employment in consumption activities has been growing faster than in the economic base and cities are becoming more alike in consumption structure. Growing evidence suggests this sector is an important engine of growth (Kay *et al.* 2007; Markusen and Schrock 2006). The studies point to the increasing importance of employment in the service sector as a link to the regional economy.

The analysis in Kay *et al.* (2007) suggests that the export-oriented emphasis of regional economic analysis suggested here excludes a large and productive sector from analysis. This is indeed a valid claim and is suggested as a framework for future research. The current analysis has merit in identifying specific sectors that are associated with ozone and provide a basis from which to understand the complex interaction between economic performance and environmental quality.

CHAPTER 4

SPATIAL ISSUES IN MATCHING ENVIRONMENTAL AND ECONOMIC DATA

4.1 Introduction

Many of the studies discussed in Chapter 2 investigate the relationship between income and pollution at a specific place, whether it is a small aggregation of counties or for a metropolitan area. Investigating the broader regional or national trends in these relationships is not simply an issue of "scaling-up" as there are data and methodological issues inherent in matching air quality data with economic data. The two most significant problems in estimating the environment - economy relationship at each of these levels are spatial variation and spatial scaling, *i.e.* where sampling data gathered at one point (typically environmental data) is not congruent with locations or spatial units by which the corresponding economic data is gathered. This chapter describes the problem and discusses some remedies available to researchers when confronted with these issues. Although these remedies were not fully employed in the final analysis, it is still worthwhile to make the issues explicit so that future researchers can make a determination as to the severity of the data limitations in their respective analyses.

The first problem is the inherent nature of sampling of environmental data. Data for ambient air quality only exist in areas where there are air quality monitors. The obvious implication of this is that there are often incomplete data sets or insufficient data points to accurately assess air quality in a given area. Since economic data is gathered uniformly across geo-political units, this leads to mismatch in the spatial scale by which different types of data are measured, requiring "rescaling" of one or both data sets. One method sometimes employed is *kriging*, which is a well-known technique in the geological and environmental sciences but less prevalent in the socio-economic literature. In the simplest sense, kriging uses the correlation structure from spatially related variables to predict observations at another location. This tool has been only modestly successful in remedying problems with air-quality data for reasons to be discussed in detail later.

Second, in both environmental and economic data, there is often a spatial correlation structure embedded within the variables. When spatial processes are present in the data, the error terms of a regression are correlated and positive auto-correlation increases the probability of false positive findings in standard significance tests (Odeland 1998). A standard correction for this spatial auto-correlation is to re-weight the variables through the use of a spatial weighting matrix*,*

The points raised in this analysis are not new; issues of spatial scale and correlation are well recognized in the literature. Considerable work has been done at the local level to correct for spatial scaling inconsistencies in hedonic pricing studies (Jerrett *et al*. 2001; Gelfand 2001; Kim *et al*. 2003). An easy correction is to bring the scale of economic data closer to the point at which air quality data is collected by using the smallest spatial unit available, such as neighborhood, census tract, city, or, in some cases, the county area (see Kahn 2000; Jerrett *et al.* 2001; Emerson 2004). For a broader spatial unit such as nations, most research focuses on estimating Environmental Kuznets Curves (EKC) for various pollutants. However, measurement error issues (due to difficulties in obtaining reliable data) are still a primary challenge for researchers (Dindha *et al.* 2000; Dindha 2004), making spatial and scale issues a secondary concern. On the regional and national levels, issues of scale remain a problem and although attempts at estimating the relationship between the environment and the economy directly are sparse, there have been some admirable attempts at estimating an environmental Kuznets curve at the household, regional or national level (Grossman *et al*. 1994; Grossman and Krueger 1995; Carson *et al.* 1997; Kahn 1998; Rupasingha *et al*. 2004).

4.2 Spatial Mismatch

A spatial mismatch problem occurs when it is necessary to make inferences about values of a variable at points or spatial units different from where it was observed. To be consistent with the literature, the correct terminology for this problem is called a 'change of support' problem where the support is simply the area or point at which the data are observed (Atkinson and Tate 2000; Gelfand *et al.* 2001). For example, the spatial support for the monitoring data is simply the location of the monitoring site but in the case of census data where data is both aggregated and zoned over the area of observation, the support is the entire area of coverage.

Commonly, economic data, gathered at the spatial unit congruent with a geopolitical boundary (*e.g.* county, census tract), are simply ascribed to the point at which the environmental data is observed (Jerret *et al.* 2001; Kahn 2000; Anselin 2003). This option necessarily lends itself well to location-specific inquiries—at the metropolitan, or preferably census tract or neighborhood level—as long as the data is available at such a detailed level the spatial mismatch problems are minimized. At this smaller spatial scale, the spatial supports, while not entirely congruent, are at a scale such that the commonly employed strategy of imputing data based on area weights is not grossly unreasonable (Gelfand *et al.* 2001). Data on housing prices, population characteristics such as race and gender and voting records are generally available at a census tract, zip code or neighborhood level, which are more easily matched to the location of a monitoring site.

The problem becomes more complex, however, when the economic data of interest is only available at the county level, as is usually the case in the U.S. because due to privacy concerns personal and firm data are aggregated. Atkinson and Tate (2000) describe the problem:

> Often, there is a need for data sampled at one scale or location to be extended or generalized to other scales or locations or perhaps combined with other data. However, the existence of scale-dependent spatial variation makes the processes of data re-scaling and data integration problematic. In particular, the commonly employed techniques of averaging, smoothing, extrapolating, and interpolating to different scales of measurement are hazardous, *particularly when combined with other problems such as replacing missing data* (emphasis added) (p. 609).

Ambient air quality is notoriously difficult to measure due to the volatile nature of climactic and atmospheric conditions, and it is even harder to generalize the measurements taken at one point over a given area. This must be considered when determining which air quality measure to match with economic variables. Ambient air quality is measured at monitoring stations controlled by the Environmental Protection Agency (EPA) and maintained by state and local governments (SLAMS), the national government (NAMS) or other organizations (PAMS). EPA administration and oversight of this SLAMS / NAMS / PAMS Network ensures continuity across measurement methodology and sets standards for conformance. The data is compiled by the EPA and made publicly available in the AIR database (formerly AIRS) (US EPA, 2002). Although AIR is arguably one of the most comprehensive air quality datasets in the world, it remains imperfect for the purposes of linking air quality to underlying economic conditions. The monitors are not uniformly placed across the U.S. (see Figure 4.1) which makes it nearly impossible to determine ambient air quality measures in areas lacking a monitoring station. Where there is missing data, the researcher must either drop data points for areas lacking monitors or find some way to extrapolate or try to accurately predict the missing values in this non-systematic air quality data.

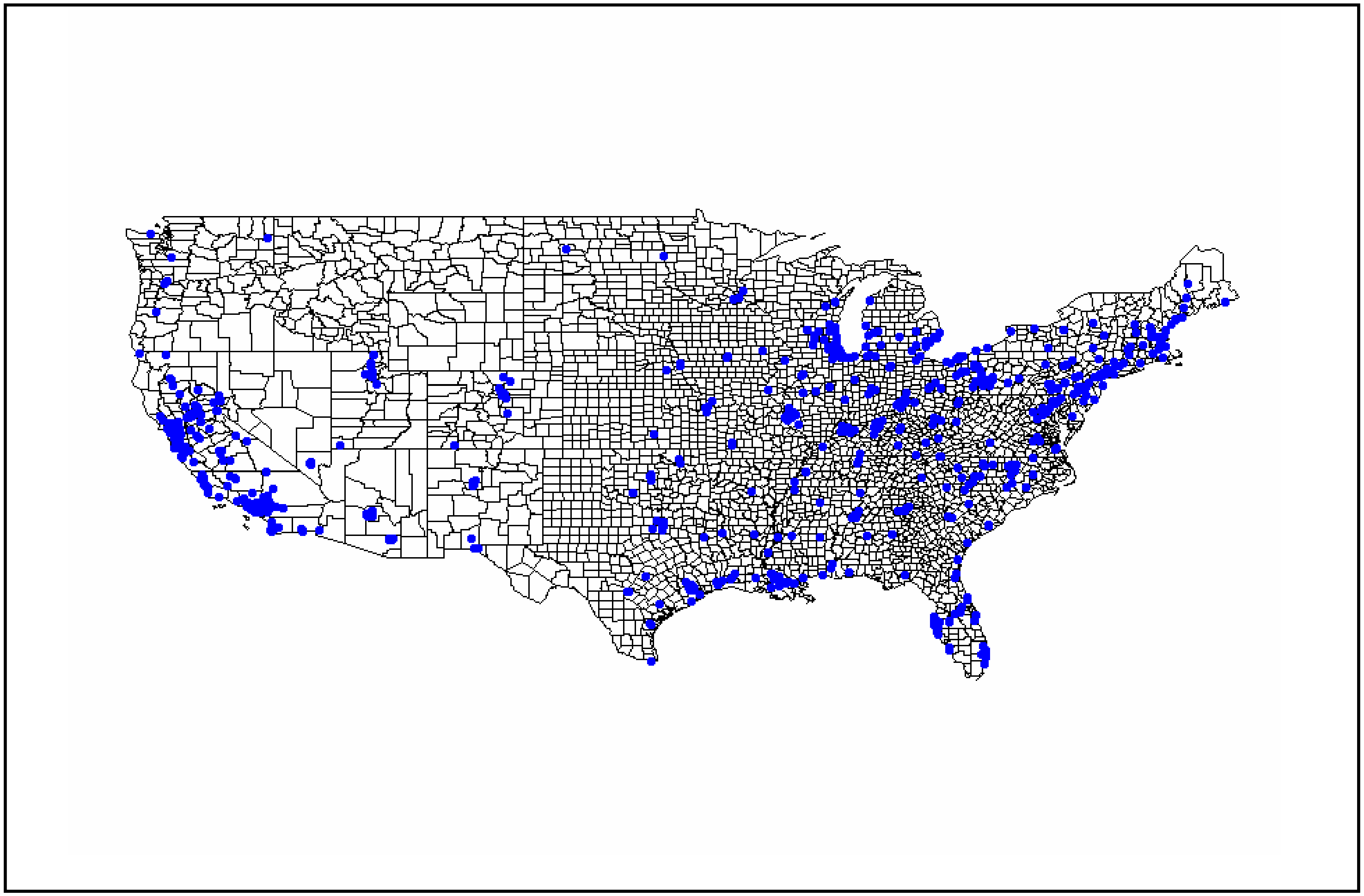


Figure 4.1. Ozone Monitoring Sites 1997

Monitor coverage is uneven for many reasons. Monitors may be placed for political and/or scientific reasons or may be placed to monitor compliance with emissions regulations or for the Prevention of Serious Deterioration (PSD)[8] (Weinberg and Reilly 1998). In metropolitan areas, observations may be taken to monitor compliance with NAAQS for ozone which is currently an 8-hour standard, meaning there cannot be more than 1 instance of an exceedance of the standard within a given 8-hour period. Figure 4.2 shows the locations of monitoring sites in 1997 with the boundaries of MSAs also denoted. Not surprisingly, the monitoring stations roughly correspond with metropolitan areas, an obvious indication that most sources of ozone are located in urban areas.

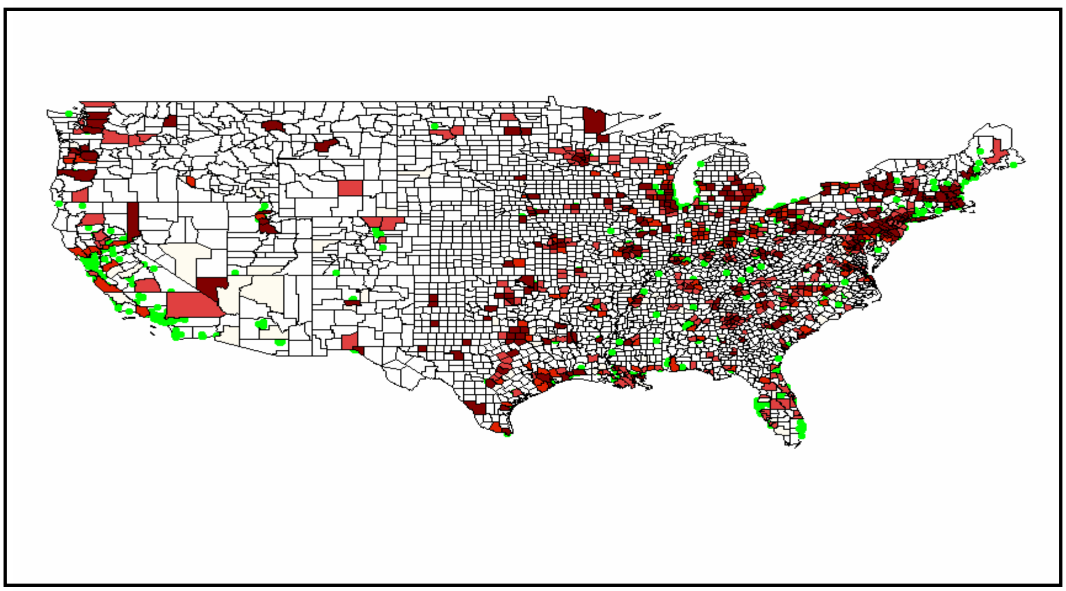


Figure 4.2 Ozone Monitoring Sites and Metropolitan Designation in 1997

[8] PSD is designated places where air quality is better than what is prescribed in the NAAQS and there is a tangible national benefit to maintain such quality, i.e. in national parks.

Due to the number of institutions involved and the inherent cost of the data gathering effort, the data are not consistent across counties or metropolitan areas. For example, the average number of observations for 1002 monitoring sites in 1995 was 565. In 1985 there were 717 sites with a mean number of observations 482. The AIR database summarizes observations from each monitoring site and provides a number of summary statistics including maximum, minimum and mean values and counts of 'exceedances.' The count of exceedances, or the number of times a county exceeds the NAAQS, is a popular indicator for air quality (see Kahn 2000) but it is only useful when the ozone levels are actually high enough to generate exceedances, and there are sufficient monitoring sites to ensure confidence in the coverage. The exceedance measure is therefore more suited to localized analyses to monitor changes over time such as that used by Kahn (2000) to monitor economic effects of changes in ozone levels in the Los Angeles Basin.

'Maximum' and 'second maximum' values representing the highest ambient ozone levels in an eight-hour period are useful indicators of the potential severity of the ozone problem. All ozone readings for a given year are averaged using both arithmetic and geometric mean methods. The arithmetic mean is used in the regression analysis in Chapter 7 because it is the most accurate indicator of overall ozone levels although there are some serious disadvantages. Figures 4.3 and 4.4 show there is considerably less variability in the mean values relative to the maximum values when plotted against non-attainment status. However, the maximum value is more strongly associated with the attainment variable (correlation coefficient=0.557) relative to the mean value with a correlation coefficient of 0.229.

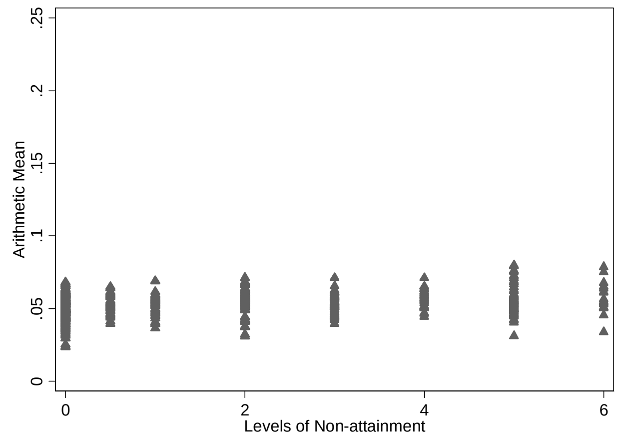


Figure 4.3 1997 Ozone arithmetic mean values and levels of Non-attainment

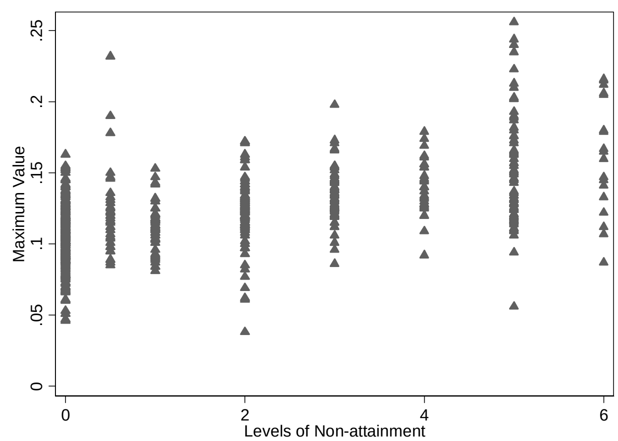


Figure 4.4 1997 Ozone maximum values and levels of Non-attainment

The AIR database calculates the arithmetic mean for a given monitor but the researcher must make a decision in how (and if) to estimate ozone levels for counties in which there is no monitor and to aggregate the data for counties in which there is more than one monitor. Researchers often simply drop the data for counties with no monitors (*e.g.*, Henderson 1998; Kahn 1999 and 2000) but a process called *kriging* is often employed to predict air quality in a county given the air quality of counties around it. I explored the kriging process for this analysis and determined that the results did not warrant incorporation into the econometric model but the technique remains promising and is described briefly below. The methodology is discussed in more detail in APPENDIX B.

The purpose of kriging in this study was to create a new predicted value of ozone *PREDMEAN* values for each county, with only one data point per county. The kriged values are then mapped onto a new dataset comprising all counties identified uniquely by the latitude and longitude values for the county centroid. There were 650 *ARITHMEAN* values used to predict the new variable, *PREDMEAN,* at 3111 county centroid sites. From the predicted values, the metropolitan counties (county categories A, B, C, D, and F from Table 3.1) were extracted to form the 877 values of *PREDMEAN.* Figures 4.5 and 4.6 show the actual and predicted values plotted against the attainment variable *ATMTEPA.* While it appears that some data points are missing, (*e.g.* in *ATMTEPA* category 6) those counties that were dropped were not metropolitan counties and were therefore dropped after the predicted values were calculated.

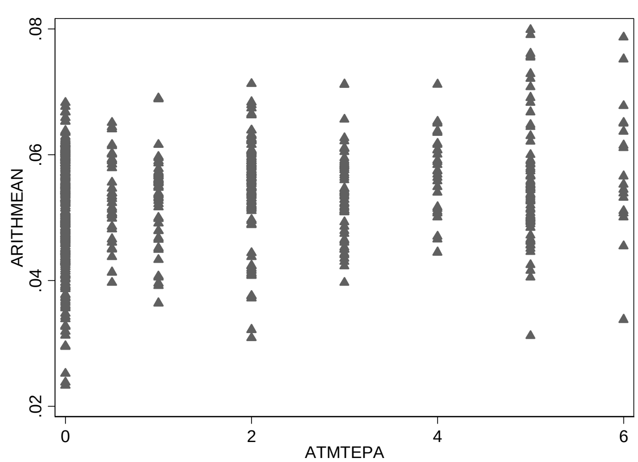


Figure 4.5 Mean values of ozone by attainment status from 650 monitoring sites

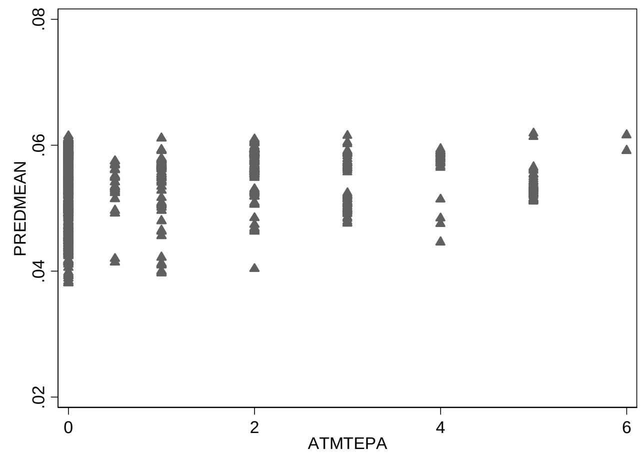


Figure 4.6 Predicted values of ozone by attainment status at 877 county centroids

The new variable, *PREDMEAN* shows much less variation than the original data and tends to underpredict mean values. This can be problematic when using this variable to test the economic effects of the presence of ozone. In this case it is preferable to underpredict rather than overpredict such that any results can be interpreted as conservative, arguably the best position given the uncertainty inherent in the analysis.

To develop a measure of air quality for counties that have more than one monitor the commonly used approach is to average the data at the county level and drop observations for counties if there are no monitors in that county (e.g., Henderson 1998; Kahn 1999 and 2000). Kriging addresses the missing data problem but the "averaging the average" problem still remains unsolved. It is acknowledged that averaging a value spatially (within the county) when it has already been averaged temporally (averaging multiple observations for a given time period) has the unintended effect of diluting the richness in the data but this can only properly be addressed by sophisticated air quality modeling.

4.3 Spatial Correlation

The presence of underlying spatial processes in the data is another issue in analysis that is found in the literature. It is widely accepted that spatially correlated errors, similar to errors correlated over time, result in a biased variance which may produce incorrect *p-values*. The basic concept behind spatially correlated error terms in the context of this analysis is best described by an example. In the case of two adjacent counties it is reasonable to expect numerous *spillovers* for a given County A from both the air quality and the presence of services in an adjacent County B. For example, if the air quality in a county is good, it is likely that this would have a positive effect on the neighboring counties by attracting people and businesses, especially those valuing clean air. Also, because the county definitions are historically defined and do not represent any typical economic characterization such as a labor or capital market, is also reasonable to expect that counties with high levels of wages, income or services might also be adjacent to each other or otherwise correlated across space.

Environmental and geological sciences have long been addressing spatial correlation issues and controls for spatial correlation are beginning to be commonly addressed in the economics literature. For example, Kim *et al.* (2003) control for spatial auto-correlation using a spatial lag model to estimate the effects of reductions of SO_2 on housing prices in the Seoul metropolitan areas. Results indicated that SO_2 pollution levels had a significant impact on housing prices and that houses in areas with a 4% improvement in mean SO_2 concentrations realized a \$2,333 premium or 1.4% of mean housing price. Rupasingha *et al.* (2004) use county-level data for toxic discharges to estimate an EKC model. Tests for spatially correlation yielded highly significant coefficients for the spatial autocorrelation parameters suggesting that statistical inference using a non-spatial specification would be invalid. Using the *spatial lag* and *spatial error* models developed by Anselin (2000) these authors find results consistent with an EKC. The authors acknowledge the limited applicability of the estimations as the data is based on emissions rather than ambient environmental quality.

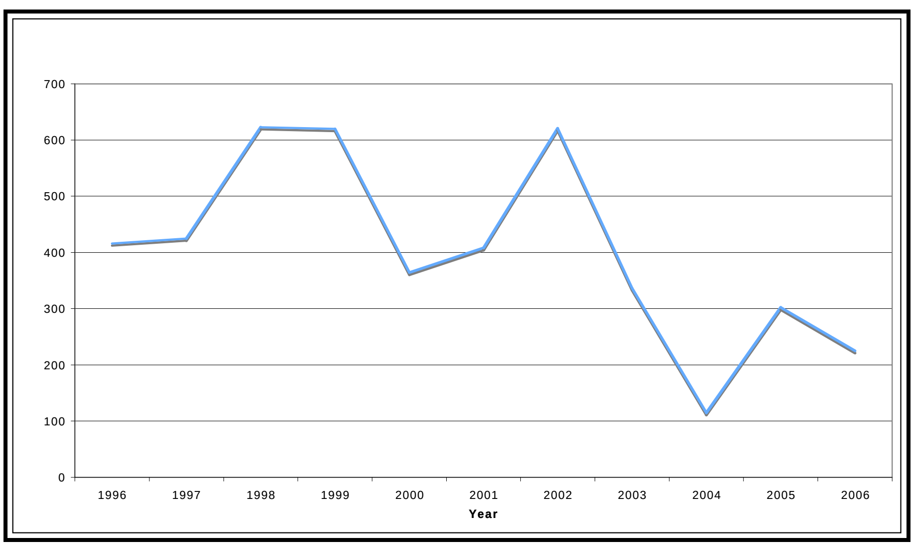
Attempts by this author to control for spatial autocorrelation yielded results that failed to change the significance of any of the variables in various regressions. A full discussion of the methodology is available in APPENDIX C and results are available upon request.

CHAPTER 5

TRENDS IN SOURCES OF SUPPLY OF POLLUTANTS: MOTORIZED VEHICLES AND GOODS PRODUCTION

5.1 Introduction

Ozone air quality improved dramatically in the thirty years since the promulgation of the Clean Air Act. As explained in Chapter 3, ambient ozone standards are set by Congress and the EPA is tasked with monitoring and enforcement. Counties that exceed the ozone standard may be deemed to be in "non-attainment" status and required to implement policies to reduce emissions. Figure 5.1 shows the reduction in the number of times counties exceeded the ozone standard between 1996 and 2006. Yet in spite of these improvements as of June 2007, 391 counties failed to attain the 8-hour ozone standard.



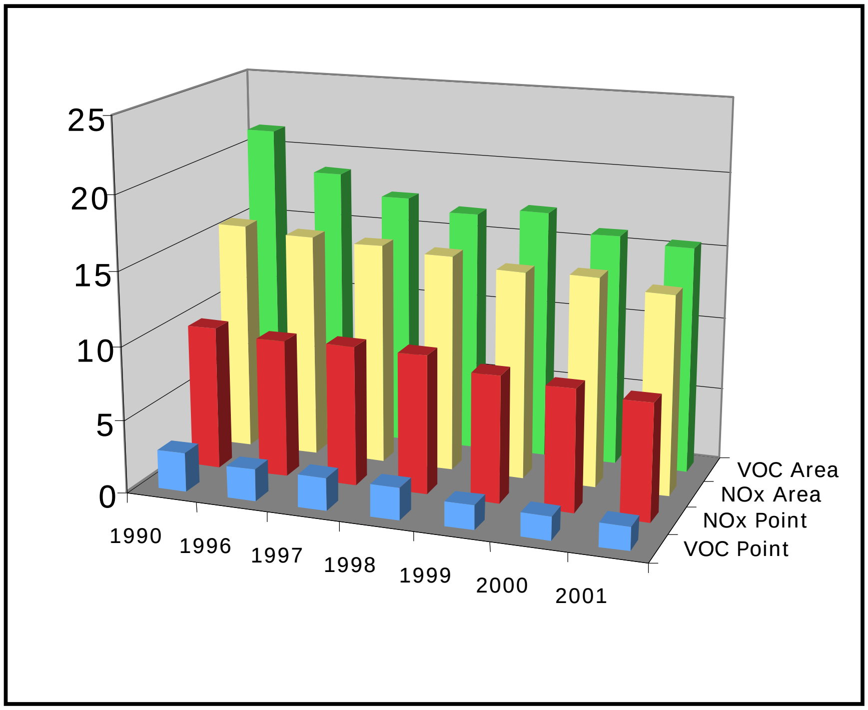
Source: US EPA Airs Database

Figure 5.1 Annual Exceedances 1996 - 2006

While the trajectory is clearly positive, the overall story for the ability to maintain ambient ozone at a level safe for human health (the primary objective of the

NAAQS standards) is not as encouraging for two reasons. First, it is widely believed that the current standard is too lenient and the EPA is recommending a revision of the ozone standard from 0.08 ppm to 0.70 – 0.75 ppm. Ozone is linked with respiratory illness, lung irritation and asthma and improved scientific research indicates that a further tightening of the standard will be necessary to protect human health. A tightening of the standard will mean more counties will again be placed in "non-attainment" status. As this will be the third revision of the standard it appears we are entering an iterative process whereby continually evolving scientific evidence forces us to reconsider what are "acceptable" levels of exposure to pollution. The persistence of the ozone problem will partially be characterized by the struggle to bring ozone levels into line with best estimates of what constitutes safe levels at a given time.

The second reason for concern about the likely persistence of the ozone problem is that the significant improvements in ozone levels to date have been achieved by reductions of emissions from point sources, namely plants, factories and manufacturing facilities. Many manufacturing enterprises either made capital investments to upgrade their abatement technology, moved or went out of business. At the same time the U.S. economy was experiencing a structural shift from manufacturing to services that naturally resulted in a decrease in emissions from point sources. With emissions from most point sources minimized to the extent possible given cost and technological constraints, planners and policy makers are focusing on achieving emissions reduction in non-point (referred to here as "area") sources such as motor vehicles. Area sources present a much more difficult regulatory challenge because "the emitter" is not a single large source of emissions that can be identified, monitored and penalized when necessary. By far the largest source of emissions of both NOx and VOCs are motor vehicles (see Figure 5.2). This large pollution source is comprised of millions of citizens and consumers who may value clean air but may not bear an immediate, individual sense of responsibility for this problem of the collective. Monitoring and enforcement costs in this group are high and, as described below, emission reductions must come from a reduction in number of miles driven or from a reduction in emissions per mile driven, or both.



Source: EPA AIR Database

Figure 5.2 Emissions of NOx and VOC by type (1990, 1996-2001)

As a reminder to the reader, ozone is formed from the chemical combination of NOx and VOCs, in the presence of sunlight. It is therefore possible that some areas may have very high aggregate levels of emissions and not have a significant ozone problem. For example, a county that has minimal sunlight and has one plant that emits large amounts of VOCs may not have significant ambient levels of ozone. It is also important to note that Figure 5.2 might be somewhat misleading because area emissions (motor vehicle emissions) are generated in every county so the sum will reflect emissions even in the most remote areas where the pollutant is easily dispersed, whereas point sources are generated only where there are operational plants. Nevertheless motor vehicle emissions are clearly the source in which there is the most potential for reduction as Figure 5.3 demonstrates.

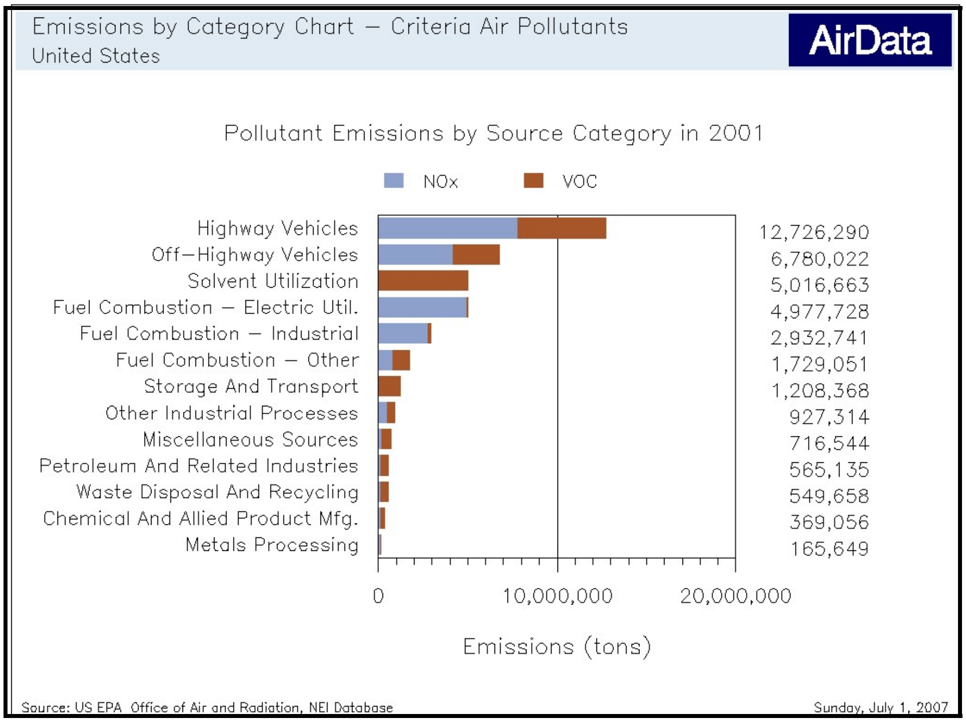


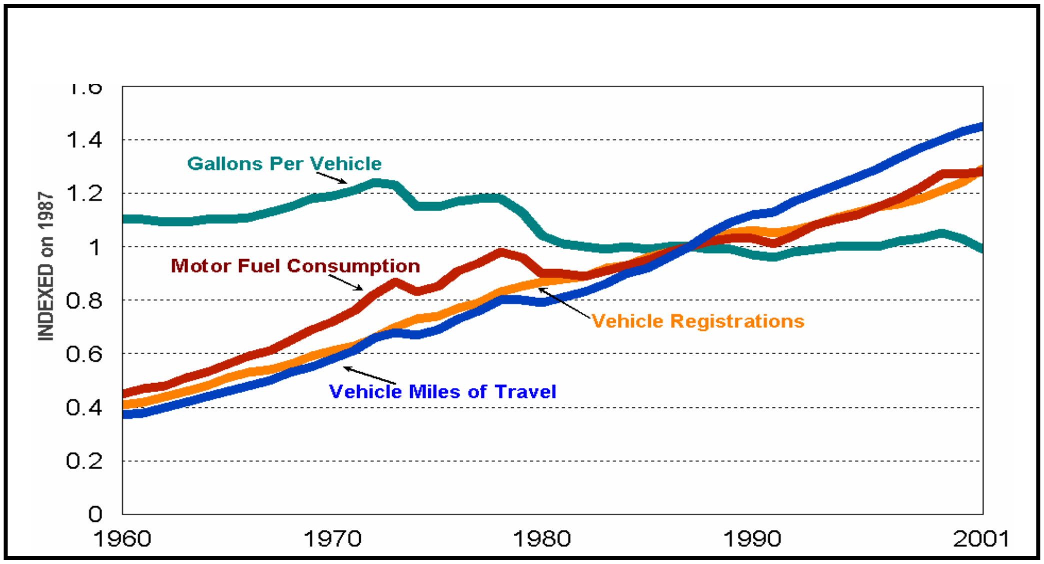
Figure 5.3 NOx and VOC emissions by source, 2001

To date, technological improvements have driven the reduction in emissions but it is not clear that improved efficiency will be a panacea into the future. The rest of this chapter further investigates trends that will affect the emissions of these two major sources of supply.

5.2 Area Emissions – Motorized Vehicles

Motor vehicle use continues to rise in the U.S. This is driven by a number of factors including increased wealth, demand for living space and other amenities that drive suburbanization, lack of investment in public transportation and a cultural preference for the convenience and privacy of individual automobiles. At the same time technological improvements have reduced the per mile emissions of most motor vehicles so that while the U.S. continues to experience between 2.0% and 3.0% annual growth in vehicle miles traveled (VMT) aggregate emissions continue to decrease.

Figure 5.4 shows increases in VMT, vehicle registrations and motor fuel consumption, indexed at 1987 levels. Only gallons of gasoline consumed per vehicle remains relatively flat over the forty-year period.



Source: US EPA Website

Figure 5.4 Vehicle Miles of Travel and other metrics of vehicle usage

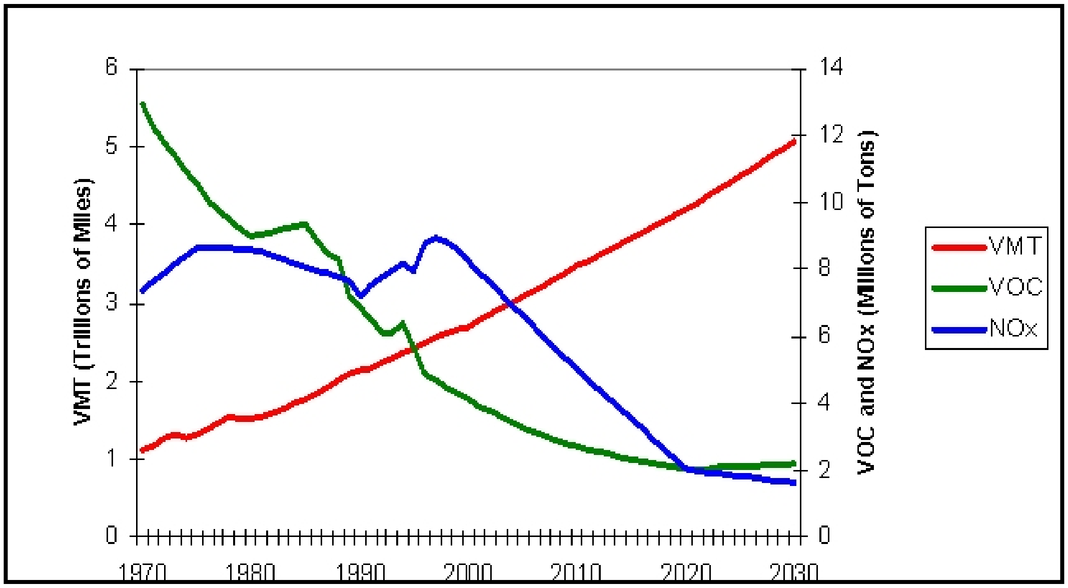
In spite of a strong environmental movement and obvious link between vehicle emissions and a number of environmental problems including the depletion of the ozone layer ("good" ozone) there is little indication VMT growth will slow and there seems to be very little political will to reverse the trend. Policy makers exude confidence that improvements in technology will continue to reduce emissions-per-vehicle-mile such as the following statement excerpted from an Air Quality Trends Analysis posted on the Federal Highway Administration website in the late 1990s:

"Air quality in the Nation's urban areas continues to improve rapidly, due largely to reductions in motor vehicles' emissions of air pollutants. Because declines in the per-mile emissions rates of motor vehicles have been so dramatic, their aggregate emissions have fallen despite rapidly increasing vehicle ownership and usage. Emissions control measures already in effect are likely to extend the decline in motor vehicles' VOC emissions for at least another decade, and further tightening of new-car emission standards could prolong this decline by approximately another ten years. In the case of NOx, tighter standards for new vehicles (including trucks as well as automobiles) are likely to be necessary to achieve the same result, although significant emissions reductions from off-road vehicles and equipment should also be possible. The experience of the past twenty-five years demonstrates convincingly that increasing travel demand and improving air quality can coexist, and continued VMT growth -- particularly at the moderate rates likely to prevail in many U.S. urban areas -- need not be an insurmountable barrier to nearly universal attainment of Federal air quality standards." (FWHA, date not available).

In 2002 a statement to the Environment & Public Works Committee of the US Senate revealed very similar rationale. The heading of the page on the Federal Highway Administration website states "Cleaner Vehicles and Fuels will result in continued reductions in vehicle pollutant emissions despite increases in travel." The statement goes on to explain:

Since 1970, aggregate emissions traditionally associated with vehicles have significantly decreased (with the exception of NOx) even as vehicle miles traveled have increased by approximately 149%. NOx emissions increased between 1970 and 1999 by 16%, due mainly to emissions from light-duty trucks and heavy-duty vehicles. However, as future trends show, vehicle travel is having a smaller and smaller impact on emissions as a result of stricter engine and fuel standards, even with additional growth in VMT (U.S. EPA 2002).

Figure 5.5 shows estimates included in this report. VMT is projected to increase by 66% between years 2000 and 2030 while aggregate emissions of *NOx* and *VOC* will decrease by 66%. Although the source of the data could not be found the chart is included here as an illustration of the optimism that technological innovation will continue to provide the reductions in emissions necessary to ensure air quality, especially in relation to ozone, continues to improve.



Source: Statement of Senator Bob Smith, Environment & Public Works Committee Hearing on Transportation & Air Quality, July 30, 2002

Figure 5.5 VMT and Emissions, 1970-2000 and 2001-2030 (Projected)

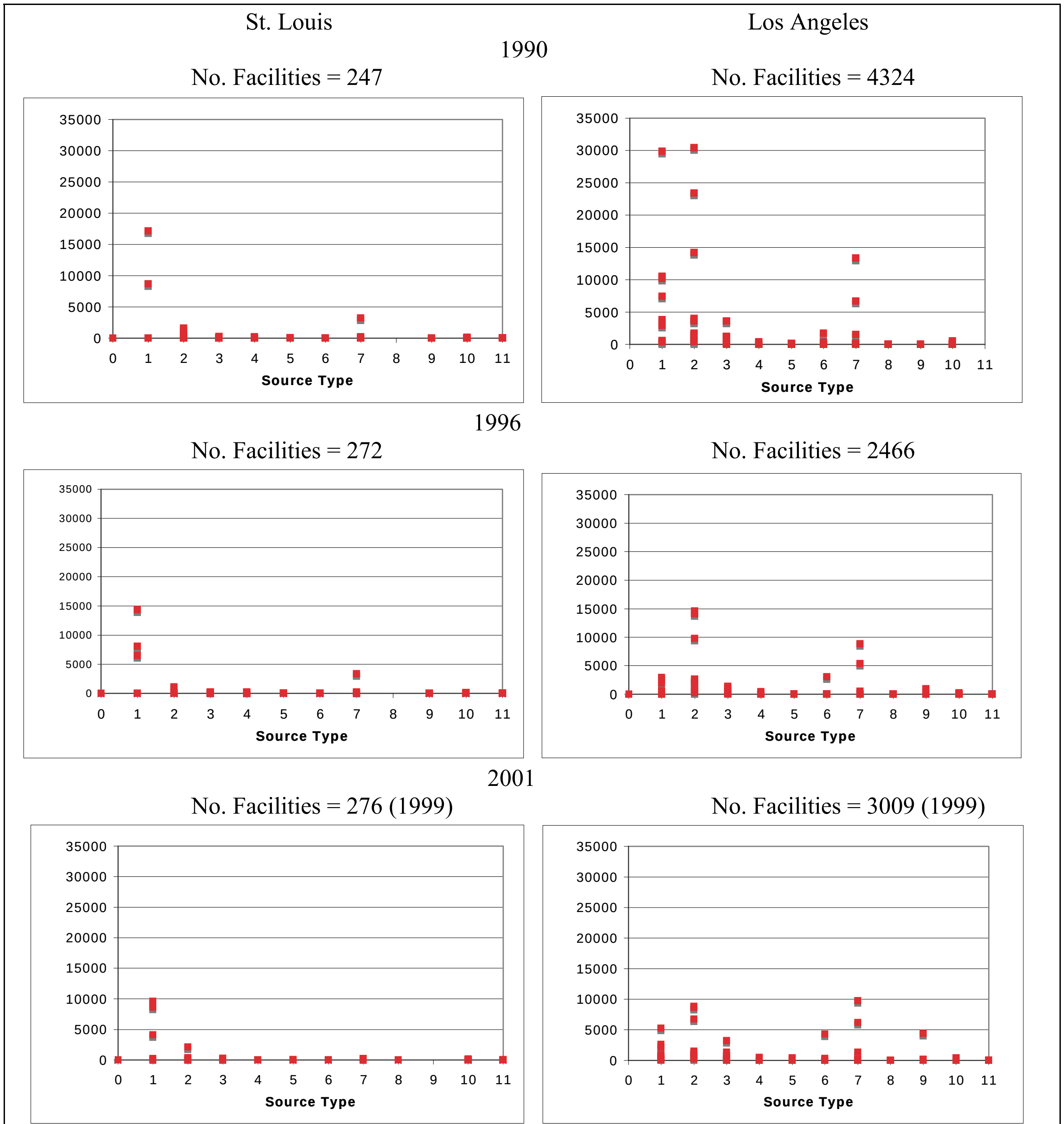
Newly promulgated EPA rules and programs, The 2004 Clean Air Nonroad Diesel Rule, The 2007 Clean Diesel Trucks and Buses Rule, issued in December 2000, and the Tier 2 Vehicle Emission Standards and Gasoline Sulfur Program will surely go some way to ensuring that new vehicles conform to tight emissions standards. Even though a complete review of the new rules and their projected effect on emissions is outside the scope of this inquiry it is important to note that compliance with the new rules requires converting fleets to new vehicles with enhanced engines. Converting capital-intensive fleets such as light and heavy trucks to new standards is expensive and industry has historically been successful in delaying expenditures on upgrades and pollution abatement equipment (for example, see American Trucking Associations *et al* vs. Environmental Protection Agency, No. 97-1440).

5.3 Point emissions

Dramatic reductions in emissions from manufacturing establishments are evident with only a cursory review of the data. This can only be explained by a decrease in per plant emissions as the aggregate number of facilities producing NOx emissions increased from 22,227 in 1990 to 30,409 in 1999 and the number of facilities producing VOCs increased from 39.777 in 1990 to 43.364 in 1999 (U.S. EPA AIR Database). It is also an indication that in spite of the decline of manufacturing as a proportion of the U.S. economy the number of polluting facilities is not decreasing. Aggregate emissions reductions are well established and readily available from the online AIR database. Two illustrative examples are provided here for the benefit of the reader.

Figure 5.6 below shows total county emissions for two metropolitan areas that have failed to attain the ozone standard since 1973, the Los Angeles metropolitan area (including surrounding counties) and the St. Louis Metropolitan area. The type of facility is listed at the bottom of the charts with "1" indicating NOx produced by electricity generating facilities and "10" indicating waste disposal and recycling plants.

The major sources of emissions for these two very different cities vary substantially. Fuel Combustion, whether for electricity generation or to fuel industrial plants, is a major source of emissions for both cities. The number of facilities in the St. Louis area actually increased over time and total emissions decreased. While



1-Fuel Combustion—Electrical Utility
2-Fuel Combustion -- Industrial
3-Fuel Combustion -- Other
4-Chemical & Allied Product Mfg
5-Metals Processing
6-Petroleum & Related Industries
7-Other Industrial Processes
8-Solvent Utilization
9-Storage & Transport
10-Waste Disposal & Recycling

Figure 5.6 NOx emissions in St. Louis; and Los Angeles by source, 1990, 1996, 2001

emissions from electricity consumption decreased substantially over time, the proportion of total emissions from electricity generation is increasing. As electricity consumption continues to increase with income in the U.S. (results available upon request) further reductions in emissions will only come if the emissions per unit of energy produced declines faster than the units of energy production increases.

With the possibility of another tightening of the ozone standard looming it is questionable whether these counties can achieve the further emissions reductions necessary. Very little data is available to calculate marginal costs of incremental reductions in emissions. The Pollution Abatement and Control Expenditures Survey (PACE) survey was discontinued by the U.S. Census Bureau in 1994 and cost data in the U.S. remains proprietary. Nevertheless it is a safe assumption that achieving further incremental reductions in point source emissions will require significant investment, which will surely be opposed by industrial producers.

While this provides a snapshot of emissions at a given time it is important to look at the evolution of the economy as these reductions were taking place. Most counties in non-attainment status dramatically reduced point source emissions and still fail to attain the ozone standard.

5.3 Trends that will affect future emissions

5.3.1 Descriptive Statistics

Recall that county wage shares are calculated according to the sectoral taxonomy and definition of wage shares as defined in Chapter 3. These wage shares are used to illustrate the relative prominence of manufacturing in county economic growth. The descriptive statistics for the five measures of the sectoral shares defined in Chapter 3: *MFG*, *DIST, PSFIN, PSOTH* and *ACS* for three years (1977, 1987 and 1997) and categorized according to the metropolitan taxonomy (A through F) are shown in Tables 5.1 and 5.2 below. Also recall the five traded goods and services sectors sum to 56% of metropolitan earnings on average. While this excludes almost half of the economy, the impact on the entire economy is accounted for because the argument here is that the traded goods and services sectors drive the metropolitan wide wage level, not all sectors. Glaeser *et al.* (1992) and Henderson *et al.* (1995) use industry employment as the basis for measuring specialization but earnings data better reflects the importance of an industry for a metropolitan area. Employment shares measure industry mix well, but they are not representative of the impact on the local economy.

The relative mix of traded goods and services sectors changed markedly for U.S. metropolitan and non-metropolitan areas over the twenty years covered by the data. Even between categories of metropolitan areas we see dramatic differences in the way the counties evolve on average. Goods production (*MFG*) continues to be the largest traded goods and services sector on average, but its relative share, measured by the mean, fell from 25.9% of metropolitan earnings in the oldest metro areas (Category A) to 18.6% in 1997. As the age of metropolitan counties decreases (Categories B-D, respectively) the initial proportion of manufacturing is lower and the decline is less marked. This makes sense if we recall that counties in Category B did not become metropolitan until the 1970s and those in Category C entered metropolitan status only in the 1980's. Although its mean share has diminished, the variation in the goods production share among metropolitan areas continues to be substantial, as measured by the coefficient of variation. Manufacturing share remained relatively constant at around 18.5% for non-metropolitan counties, with the highest coefficient of variation of all of the categories.

Table 5.1 Descriptive statistics for sectoral shares in A, B and C county categories

	A (Oldest Metro) n=352			B (Metro in 1970) n=108			C (Metro in 1980) n=259		
	1977	**1987**	**1997**	**1977**	**1987**	**1997**	**1977**	**1987**	**1997**
Manufacturing (MFG)									
Mean	0.259	0.218	0.186	0.250	0.238	0.218	0.249	0.235	0.214
Std Dev	0.141	0.117	0.103	0.138	0.135	0.123	0.152	0.141	0.131
Min	0.001	0.000	0.001	0.027	0.031	0.028	0.000	0.022	0.018
Max	0.793	0.714	0.586	0.656	0.676	0.551	0.715	0.625	0.686
COV	0.542	0.536	0.553	0.551	0.568	0.565	0.613	0.603	0.612
Producer Services Financial (PSFIN)--Services include Banking, Finance									
Mean	0.045	0.054	0.066	0.033	0.036	0.049	0.013	0.034	0.044
Std Dev	0.023	0.030	0.038	0.019	0.026	0.032	0.014	0.017	0.022
Min	0.000	0.000	0.000	0.008	0.010	0.012	0.000	0.000	0.000
Max	0.194	0.273	0.371	0.180	0.247	0.274	0.097	0.104	0.165
COV	0.511	0.553	0.576	0.580	0.711	0.655	1.025	0.501	0.504
Producer Services Other (PSOTH)—Services include Accounting, Engineering, Architecture									
Mean	0.058	0.087	0.116	0.042	0.059	0.074	0.042	0.057	0.072
Std Dev	0.030	0.044	0.059	0.020	0.026	0.03	0.025	0.033	0.040
Min	0.005	0.000	0.002	0.012	0.017	0.023	0.000	0.013	0.019
Max	0.222	0.271	0.383	0.120	0.162	0.179	0.190	0.250	0.387
COV	0.520	0.510	0.509	0.475	0.439	0.412	0.603	0.569	0.554
Advanced Consumer Services (ACS)—Services include Health Care, Theme Parks etc.									
Mean	0.068	0.087	0.112	0.052	0.066	0.077	0.049	0.063	0.086
Std Dev	0.025	0.032	0.042	0.028	0.037	0.031	0.024	0.032	0.041
Min	0.000	0.000	0.000	0.011	0.014	0.007	0.000	0.006	0.003
Max	0.202	0.250	0.337	0.251	0.328	0.172	0.118	0.180	0.202
COV	0.376	0.374	0.373	0.535	0.550	0.404	0.485	0.505	0.473
Distribution (DIST)									
Mean	0.106	0.101	0.095	0.087	0.089	0.085	0.083	0.081	0.077
Std Dev	0.052	0.047	0.044	0.069	0.069	0.054	0.042	0.044	0.042
Min	0.001	0.000	0.003	0.011	0.013	0.023	0.000	0.004	0.000
Max	0.395	0.455	0.466	0.638	0.583	0.414	0.316	0.302	0.280
COV	0.496	0.461	0.467	0.787	0.771	0.641	0.505	0.538	0.548
Sum	0.636	0.547	0.569	0.464	0.488	0.503	0.436	0.483	0.493

Table 5.2 Descriptive statistics for sectoral shares for D, E, and F county categories

	D (Metro in 1990) n=106			E (Non Metro) n=2207			F (Lost Metro Status) n=75		
	1977	**1987**	**1997**	**1977**	**1987**	**1997**	**1977**	**1987**	**1997**
MFG									
Mean	0.228	0.220	0.205	0.186	0.188	0.183	0.251	0.248	0.232
Std Dev	0.161	0.150	0.143	0.155	0.154	0.142	0.148	0.151	0.145
Min	0.002	0.005	0.004	0.000	0.000	0.000	0.004	0.000	0.004
Max	0.669	0.632	0.635	0.767	0.815	0.723	0.624	0.664	0.687
COV	0.706	0.682	0.698	0.834	0.818	0.777	0.591	0.607	0.625
PSFIN									
Mean	0.032	0.035	0.042	0.030	0.029	0.034	0.031	0.029	0.038
Std Dev	0.020	0.019	0.024	0.014	0.015	0.020	0.016	0.019	0.024
Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.153	0.127	0.145	0.136	0.143	0.209	0.091	0.117	0.126
COV	0.625	0.548	0.574	0.469	0.526	0.578	0.526	0.634	0.636
PSOTH									
Mean	0.038	0.053	0.069	0.034	0.037	0.047	0.034	0.041	0.050
Std.Dev	0.020	0.029	0.041	0.026	0.024	0.040	0.021	0.022	0.021
Min	0.002	0.010	0.013	0.000	0.000	0.000	0.000	0.003	0.011
Max	0.106	0.146	0.333	0.685	0.493	0.914	0.140	0.118	0.134
COV	0.523	0.550	0.599	0.754	0.650	0.844	0.622	0.528	0.418
ACS									
Mean	0.048	0.059	0.083	0.042	0.051	0.068	0.043	0.051	0.080
Std Dev	0.028	0.036	0.048	0.028	0.033	0.046	0.022	0.027	0.082
Min	0.002	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.192	0.208	0.237	0.519	0.537	0.629	0.090	0.128	0.692
COV	0.586	0.610	0.574	0.673	0.654	0.676	0.507	0.532	1.030
DIST									
Mean	0.084	0.077	0.067	0.091	0.085	0.082	0.079	0.076	0.071
Std Dev	0.039	0.035	0.031	0.051	0.049	0.051	0.035	0.040	0.038
Min	0.006	0.008	0.006	0.000	0.000	0.000	0.000	0.010	0.005
Max	0.219	0.195	0.195	0.412	0.491	0.541	0.173	0.243	0.193
COV	0.466	0.459	0.469	0.563	0.574	0.624	0.445	0.528	0.534
Mean Sum	0.508	0.444	0.457	0.352	0.451	0.420	0.423	0.500	

In 1977, the distribution sector was the second largest of the five traded goods and services sectors across all county categories. The highest mean share of earnings of 10.6% was found in the oldest metropolitan areas although the non-metropolitan counties had only a slightly lower distribution proportion at 9.1%. By 1997 the metropolitan wage composition was very different. The three remaining sectors, all the traded services, not traded goods production (*MFG*) or the transport and sale of goods (*DIST*), increased their mean relative share of county earnings. The financial sector (*PSFIN*) increased the least: from 4.5% to 6.6% in Category A while the other producer services sector (*PSOTH*) doubled its mean share, from 5.8% to 11.6%.

The advanced consumer services sector (*ACS*) increased from 5.8% to 11.8%. Thus in 1977 a county economy that had been metropolitan for many years (Category A) derived 36% of its earnings from producing and distributing goods (*MFG* plus *DIST*), and 17% of its earnings from traded services (*PSFIN, PSOTH*, and *ACS*). By 1997 the traded goods and distribution part had fallen to an average of 29%, while the traded services part had risen to an average of 29%. This post-industrial economic shift also occurs in the counties that became metropolitan after 1970 but the transition is far less dramatic. In 1977 these counties derived 27.8% of goods of wage earnings *MFG* and *DIST* and in 1997 the average remained at 26.5%. In the services sector, in 1977 the services comprised 10.6% of wage earnings while in 1997 it was 14.9%. Changes in the composition of traded goods and services earnings among U.S. metropolitan areas generally mirror the changing composition of aggregate national and international demand over that period (Drennan 1999) but how the pattern differs in attainment and non-attainment counties will be discussed in the next section.

The sectoral wage shares represent the economic distribution of the county economies, but do not illustrate how establishments and earnings are concentrated or dispersed within a county. For example, a county where 20% of employment share is derived from the manufacturing sector but has only one employer will be very different from a county that derives 20% of county wages from manufacturing coming from 15 different establishments. Therefore a widely used measure of concentration and dispersion, the Herfindahl's index (Vogt and Barta 1997) is employed:

$$h_i = \sum_{j=1}^{n} \left(p_{i,j} \right)^2, \tag{5.1}$$

where $p_{i,j}$ is the proportion of total number of establishments in county *i* accounted for by establishments in that county belonging to sector *j*. County Business Patterns provides aggregate number of establishments, employment and payroll for 72 sectors in each county.

There are two ways to measure this concentration, in the number of firms in the sector for each county or the number of employees. The number of establishments in each sector is available for all counties and all sectors but the number of employees may be 'flagged' to avoid inadvertently revealing proprietary information. However, the data flags are partitioned according to the number of employees. To try to extrapolate this information, we use the lower bound of each category and multiply that by the number of firms that are flagged. For example, if in county *i* there is a data flag of 2 in the 5-10 employees category in sector *j* then the estimated number of employees in sector *j* is 2 x 5 or 10 employees. This provides a conservative estimate of the number of employees in that sector for each county. A Herfindahl index of 2 would mean that sectors are equally represented in the county economy. A value close to zero indicates that the county economy tends to be dominated by near monopolistic firms in each of the represented sectors. Table 5.3 reports the Herfindahl index using both number of establishments and estimated number of employees.

Table 5.3 Herfindahl Index by metropolitan category for 1977, 1987 and 1997

	A (Oldest Metro)			B (Metro in 1970)		
	1977	**1987**	**1997**	**1977**	**1987**	**1997**
Estabs-Concentration						
Mean	0.040	0.040	0.041	0.042	0.041	0.042
Std. Dev	0.034	0.056	0.039	0.007	0.011	0.013
CoV	0.856	1.390	0.950	0.172	0.266	0.311
Employees-Concentration						
Mean	0.050	0.047	0.053	0.069	0.060	0.061
Std. Dev	0.027	0.017	0.022	0.050	0.040	0.034
CoV	0.545	0.356	0.420	0.727	0.672	0.551
	C (Metro in 1980)			D (Metro in 1990)		
	1977	**1987**	**1997**	**1977**	**1987**	**1997**
Estabs-Concentration						
Mean	0.043	0.041	0.041	0.044	0.041	0.041
Std. Dev	0.009	0.006	0.006	0.007	0.006	0.005
CoV	0.201	0.158	0.135	0.158	0.142	0.117
Employees-Concentration						
Mean	0.076	0.061	0.061	0.080	0.070	0.070
Std. Dev	0.055	0.025	0.022	0.056	0.052	0.055
CoV	0.722	0.418	0.366	0.694	0.749	0.789
	E (Non Metro)			F (Lost Metro Status)		
	1977	**1987**	**1997**	**1977**	**1987**	**1997**
Estabs-Concentration						
Mean	0.050	0.045	0.045	0.055	0.043	0.042
Std. Dev	0.041	0.020	0.019	0.013	0.012	0.01
CoV	0.824	0.439	0.412	0.233	0.272	0.230
Employees-Concentration						
Mean	0.103	0.093	0.093	0.089	0.079	0.083
Std. Dev	0.093	0.061	0.064	0.073	0.065	0.079
CoV	0.898	0.658	0.690	0.816	0.827	0.960

There is very little variation across categories A through F for the Herfindahl index for establishments denoted as *Estabs-Concentration.* However, the data using the *Employees-Concentration* methodology provides the expected results. The counties which became metropolitan earliest (Category A) show the lowest proportion of diversity, a modest indication of specialization, while the smaller and less dense metropolitan counties (Categories B-D) become increasingly less diverse depending on the time period in which they became metropolitan. It is worth noting that in all categories, the Herfindahl index declines over time, indicating a trend toward specialization as the population increases.

Finally, a few facts are assumed in the following discussion. County Categories (A-D) are proxies for income and density and that their ordinal ranking is invariant over time with Category A counties having the largest average wealth (as measured by *PCPI)* and population density. The descriptive statistics for these variables will be presented in the next chapter; the relevant fact for this chapter is the relative ranking structure. It is not surprising given that county area is fixed, making population density directly dependent on population. Figure 5.7 shows that the metropolitan category is a good proxy for urban form with category A counties representing the dense and highly populated areas with category E representing more sparsely populated non-metropolitan areas.

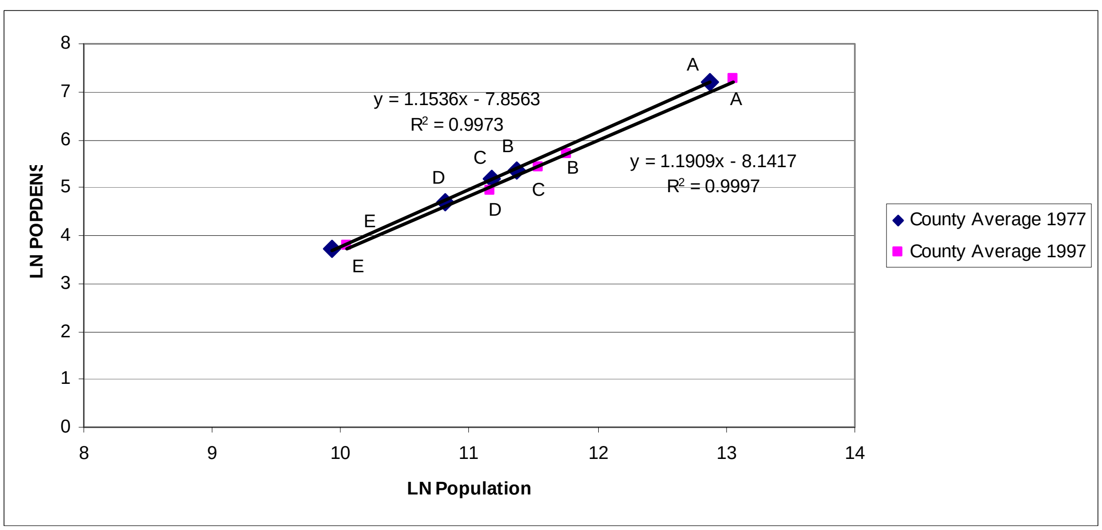


Figure 5.7 Average population and average population density by metropolitan category, 1977, 1997

Conveniently, a similar relationship holds for Per Capital Personal Income *(PCPI)* (see Figure 5.8). It is therefore not too abusive to consider metropolitan age as a broad proxy for density and income.

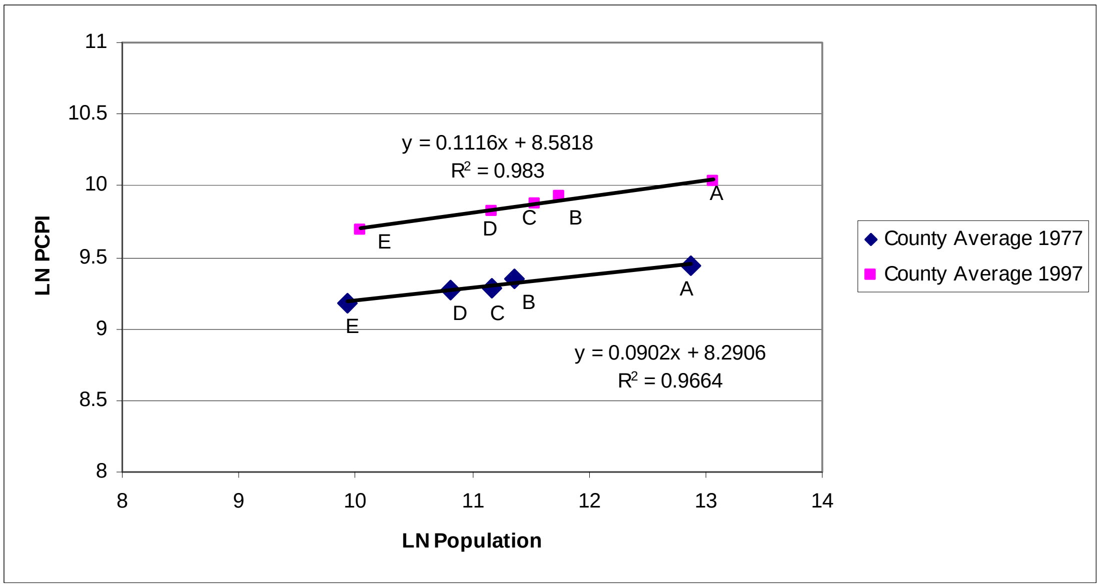


Figure 5.8 Average population and average PCPI by metropolitan category, 1977 and 1997

5.3.2 Industry Lifecycle

The results from Table 5.1 and 5.2 reveal a decline in manufacturing relative to service industries but does not reveal how non-attainment status might alter the pace of the transition. If we assume that service sector jobs are associated with a higher quality of life (an assertion explored in more detail in the next chapter), it might be reasonable to hypothesize that service sector industries might grow faster in attainment areas where air is cleaner and there are fewer restrictions or costs to vehicle travel. However, the well-established fact of urban external economies of scale, whereby external benefits from physical proximity to other firms accrue to the firm through increased productivity, seems to contradict this hypothesis. There are two types of economies of scale, urbanization and localization economies. Urbanization economies are benefits derived from operating in a larger urban environment where there is a larger pool of labor and a larger variety of goods and services available to support a firm and its employees. Localization effects are those benefits which firms accrue locally through the economies of specialization *e.g.,* a significant presence of one industry in an area allows firms to specialize to a larger degree than they would be able to do if there were not similar firms nearby (Henderson 1988). Because this data is an aggregation of wage shares across a county it is not possible to determine whether the benefits of scale are due to urbanization or localization economies, so for the purposes of this analysis the focus is on identifying possible benefits of scale economies and leave identification of the *type* of scale economy to future work.

I analyze how the composition changes differently across attainment and non-attainment counties and helps us to predict what types of county categories might be likely to continue ozone production. While these sectoral categories represented here are much broader than an individual industry, they still capture the changes in presence of one sector in an area and we are not concerned with specific industries, but rather the groupings of related industries that the sectors represent. More importantly it captures the importance of a sector in a county *relative* to other sectors.

Reviewing Figures 5.9 – 5.16 (and from the Descriptive Statistics in Tables 5.1 – 5.2 above) most county categories had an average *MFG* wage share of approximately 0.25 in 1977. The total decline in *MFG* over the twenty-year time period is given by the ‘percent change’ noted directly above each plot. In county Category A, the largest and oldest metropolitan areas, the share of manufacturing wages declined by 6.07% in attainment counties and 9.30% in non-attainment counties. A dramatic difference between attainment and non-attainment counties is found again in Category C where in non-attainment counties manufacturing declined by 5.90% and in non-attainment counties manufacturing declined by 2.74%.

Likewise, in both county categories, *PSOTH* increased more overall in non-attainment counties, increasing by 7.46% in Category A non-attainment categories and 4.5% in Category C non-attainment counties. It is interesting to note the strong deviation from this trend in Category B where the average starting *MFG* for non-attainment counties was only 0.20 and the decline was a relatively modest 1.80%. Taken as a whole, the plots show that manufacturing declines faster in non-attainment counties and the businesses that focus on providing services to producers (*PSOTH)* grows more quickly in non-attainment counties than in attainment counties. Whether this is a direct result of regulation is not clear but does illustrate the much more dramatic sectoral transformation in counties subject to attainment regulations.

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	1.64%	4.76%	-6.07%	4.42%

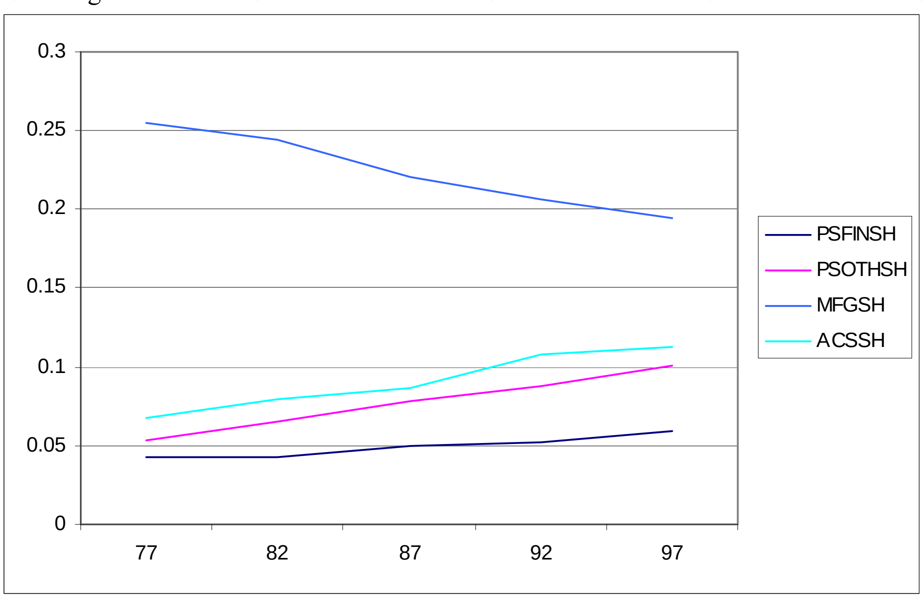


Figure 5.9 Sectoral shares over time in Category A Attainment

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	2.82%	7.43%	-9.30%	3.92%

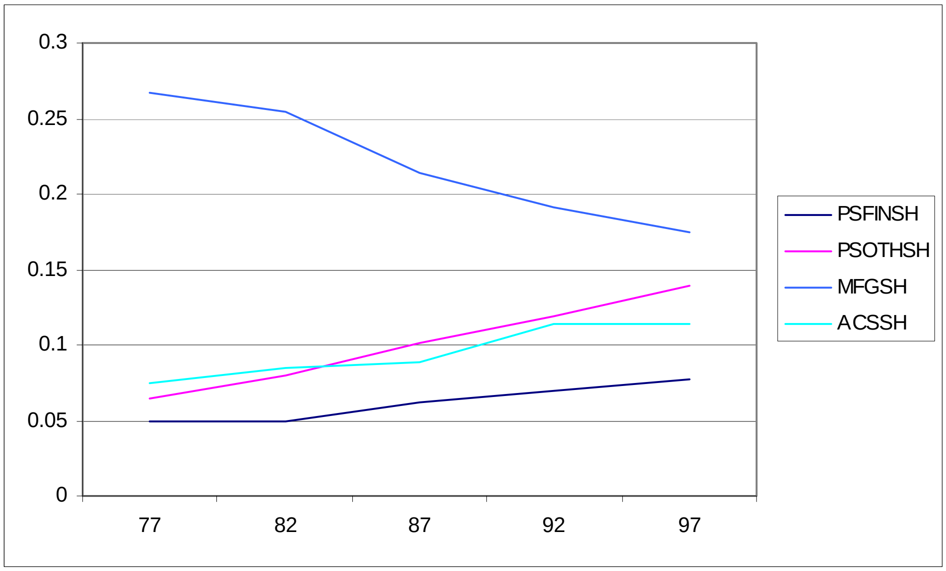


Figure 5.10 Sectoral shares over time in Category A Non-Attainment

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	1.51%	2.79%	-3.69%	2.85%

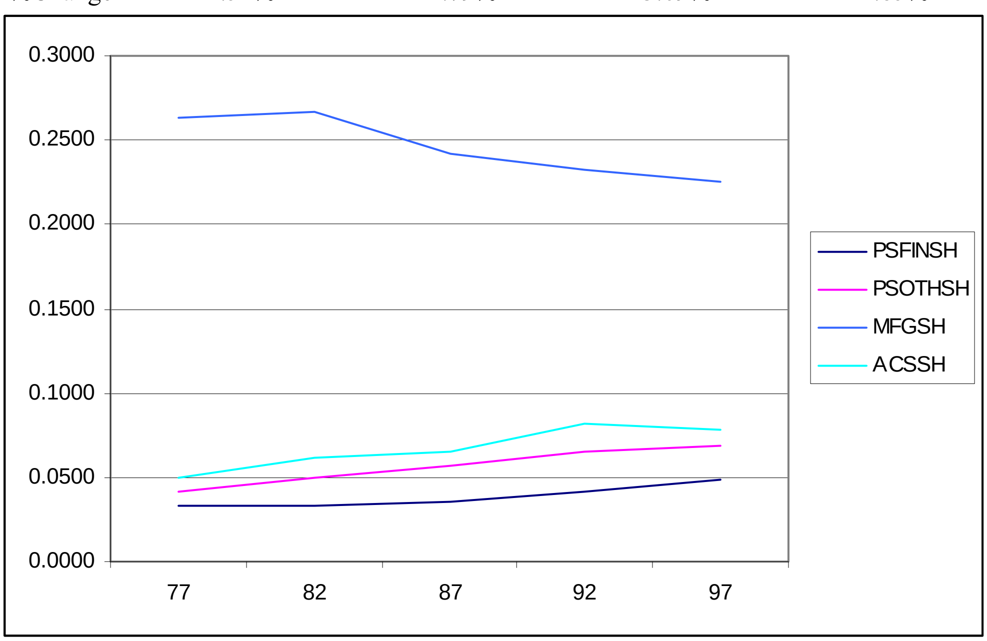


Figure 5.11 Sectoral shares over time in Category B Attainment

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	1.71%	4.34%	-1.80%	1.87%

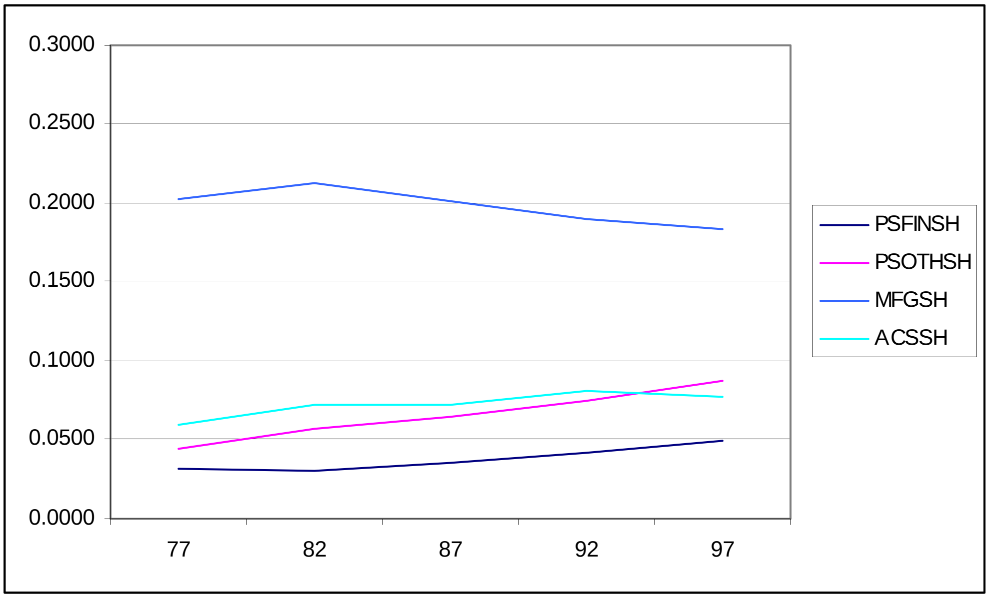


Figure 5.12 Sectoral shares over time in Category B Non-Attainment

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	1.06%	2.83%	-2.74%	3.66%

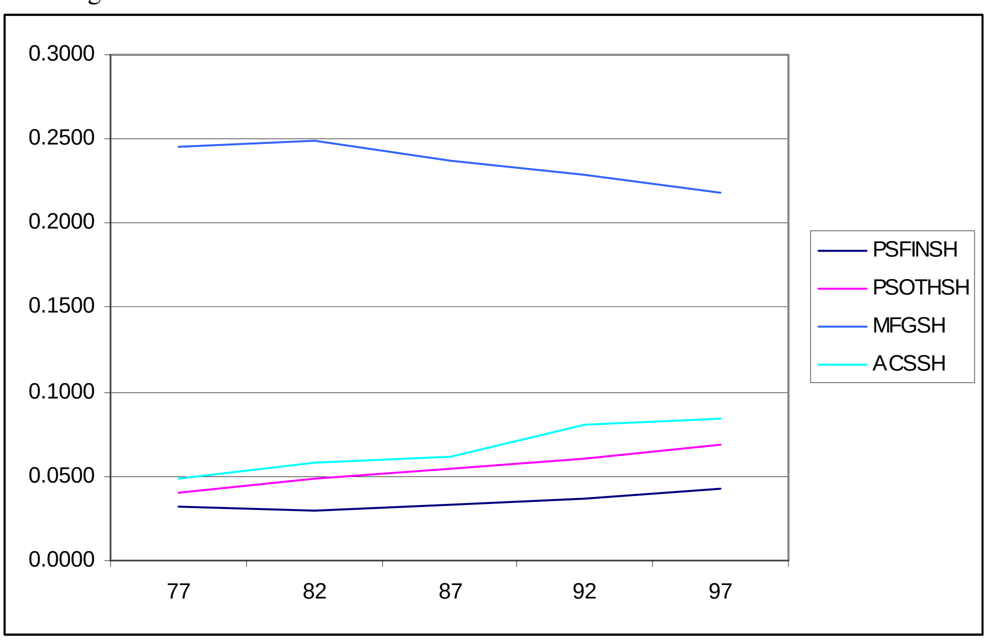


Figure 5.13 Sectoral shares over time in Category C Attainment

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	1.74%	4.50%	-5.90%	3.79%

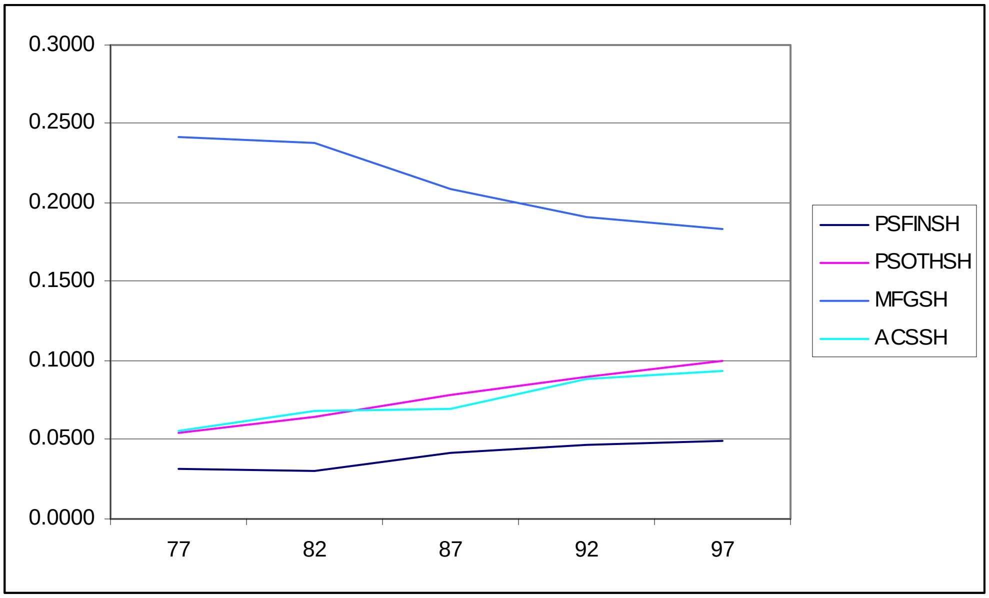


Figure 5.14 Sectoral shares over time in Category C Non-Attainment

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	1.07%	2.97%	-2.10%	3.45%

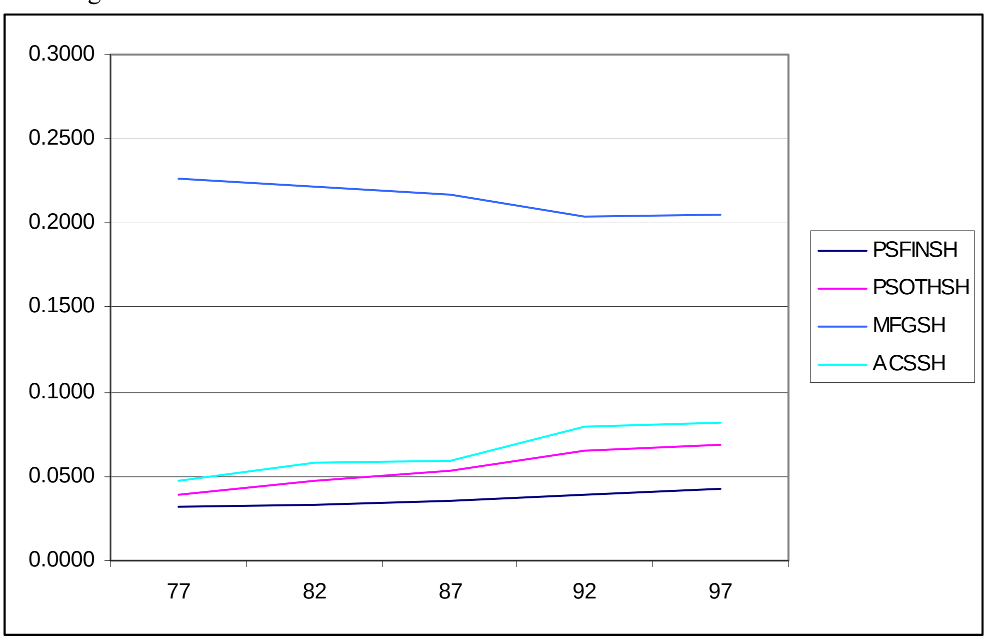


Figure 5.15 Sectoral shares over time in Category D Attainment

	Producer Services Financial (PSFIN)	Producer Services Other (PSOTH)	Manufacturing (MFG)	Advanced Consumer Services (ACS)
%Change	0.36%	2.87%	-1.43%	3.01%

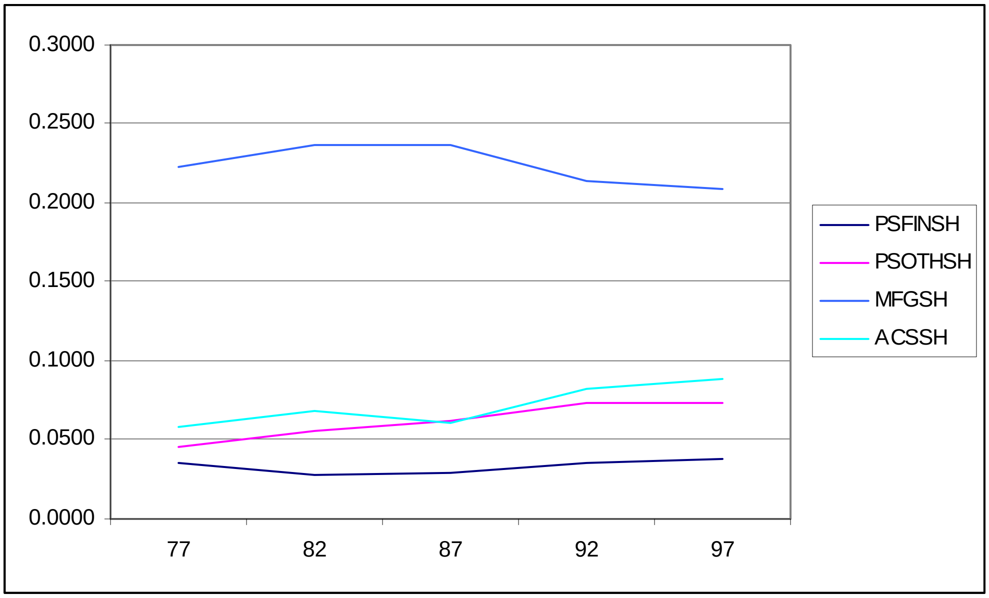


Figure 5.16 Sectoral shares over time in Category D Non-Attainment

These lifecycle curves are next analyzed in a different format to reflect mean growth rates of the sectoral shares and then test which differences are statistically significant. In Figures 5.17 – 5.20 and Tables 5.3 – 5.7 results are shown which compare the five-year growth rates by county category and attainment status (recall 0 = attainment and 1 = nonattainment). The year stated on the chart represents the final year of the five year growth interval so that the data in the “82” bin represents the growth rate for that sector between the years 1977-1982. Note that these charts depict five-year growth rates and not overall growth rates as indicated in Figures 5.13 - 5.16 so there will not be congruency in growth rates. Analyzing at five year intervals provides more detail and a better understanding of the over dynamics of the sector over time.

Figure 5.17 depicts strong growth in attainment counties in the 1987-1992 time period and the differences are statistically significant in B and C counties. This coincides with the rise in electronic processing and call-centers which would find access to cheaper labor and land rents in the newer metropolitan areas preferable to older metropolitan areas. In terms of manufacturing wage shares (Figure 5.18), there is notable negative growth in non-attainment counties, and the differences between attainment and non-attainment counties are statistically significant in many categories. In the producer services, the financial sector (Figure 5.19) exhibits positive growth in the later years in both categories but the non-attainment counties capture the majority of overall growth. By 1997 however, the growth rates equalized and in category C categories, attainment counties experienced more growth. Figure 5.19 depicts significantly different positive growth in the oldest non-attainment metropolitan areas (the converse of what was observed for *ACS*), but again this equalizes by 1997. The most striking result is that the difference between category B attainment and non-attainment counties is only statistically significant in the year 1997 for *PSOTH.* What is notable overall is the unusual results for category B counties where there are very few instances where the differences between attainment and non-attainment counties are significant. This may be an indication that the regulations affect category B counties differently (*e.g.* are neutral) or simply an artifact of the fewer number of observations in category B (and arguably not enough to ensure statistical validity), there are only 84 attainment counties and 22 non-attainment counties while in category A there are 209 attainment counties and 140 non-attainment counties.

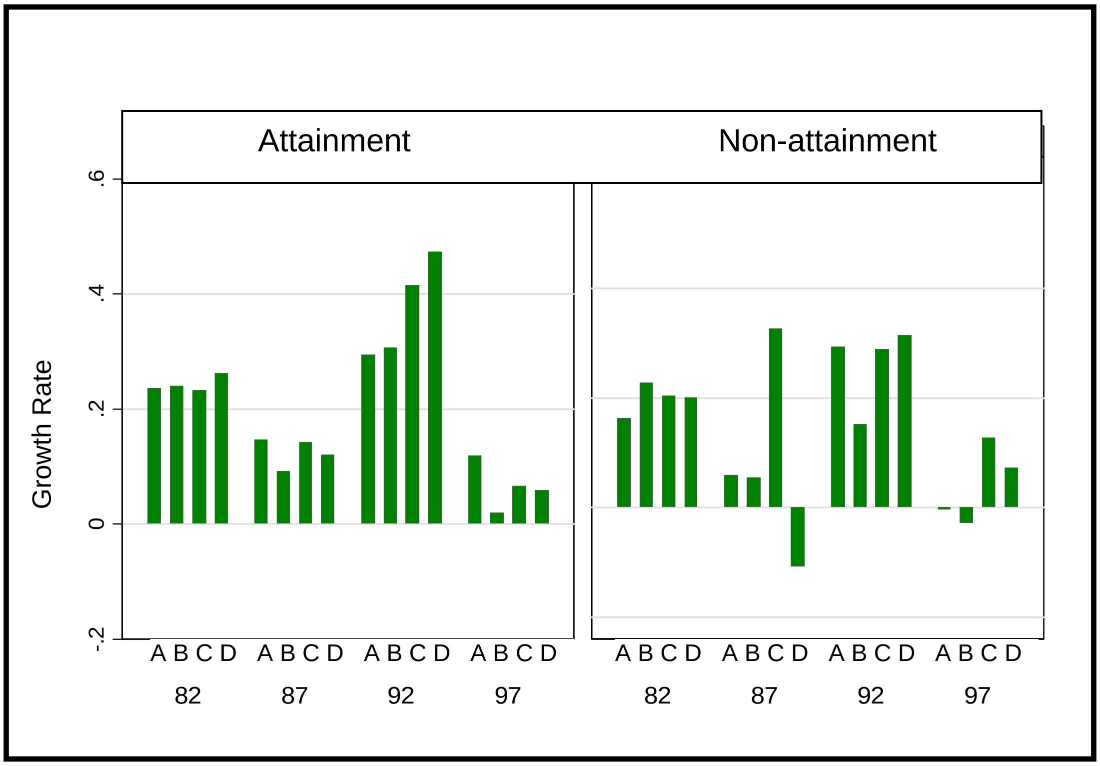


Figure 5.17 Growth rates of Advanced Consumer Services by year, county category and attainment status

Table 5.4 T-Test for difference in Advanced Consumer Services mean growth tate

Metro Category Category	82	87	92	97
Overall	Yes*	No	Yes	Yes
A	Yes	No	No	Yes
B	No	No	Yes	No
C	No	No	Yes	No
D	No	Yes	No	No

*Yes indicates statistically significant difference in means at the 95% confidence level

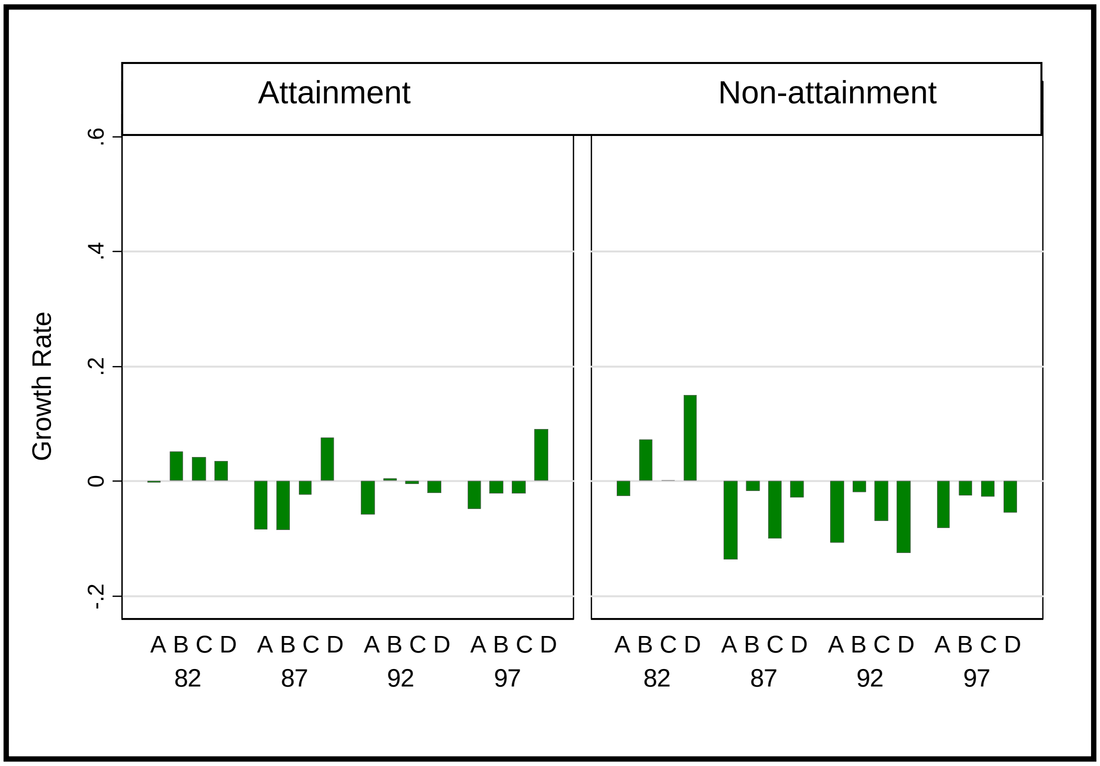


Figure 5.18 Growth rates of Manufacturing by year, county category and attainment status

Table 5.5 T-Test for difference in Manufacturing mean growth rate

Metro Category	82	87	92	97
Overall	Yes*	Yes	Yes	Yes
A	No	Yes	Yes	Yes
B	No	No	No	No
C	No	Yes	Yes	No
D	No	No	Yes	Yes

*Yes indicates statistically significant difference in means at the 95% confidence level

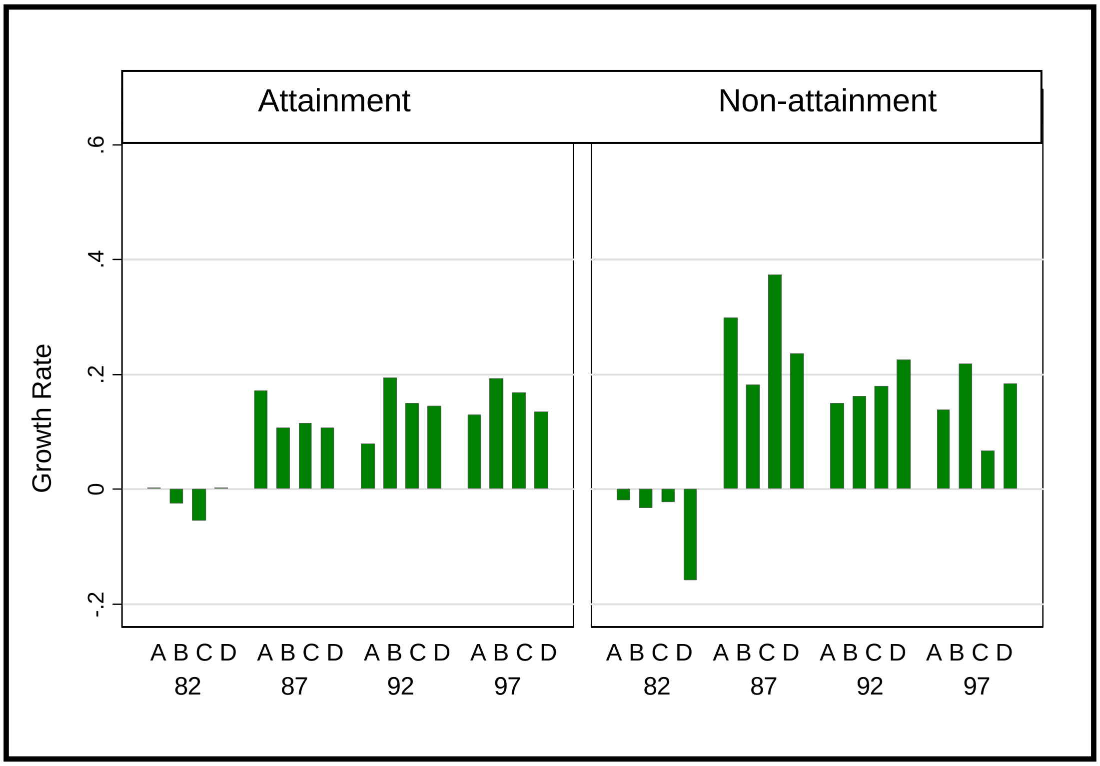


Figure 5.19 Growth rates of Producer Services Financial by year, county category and attainment status

Table 5.6 T-Test for difference in Producer Services Financial mean growth rate

Metro Category	82	87	92	97
Overall	No	Yes*	Yes	No
A	No	Yes	Yes	No
B	No	No	No	No
C	No	Yes	No	Yes
D	No	No	No	No

*Yes indicates statistically significant difference in means at the 95% confidence level

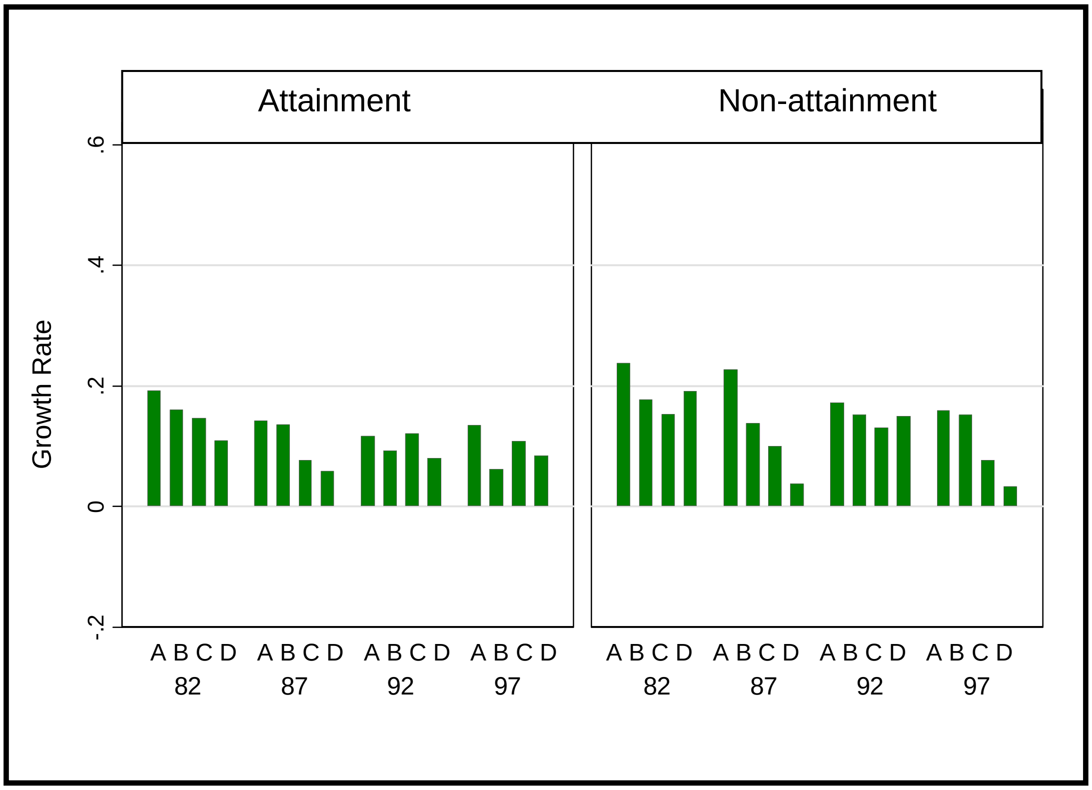


Figure 5.20 Growth rates of Producer Services Other by year, county category and attainment status

Table 5.7 T-Test for difference in Producer Services Other mean growth rate

Metro Category Category	82	87	92	97
Overall	No	Yes*	No	No
A	Yes	Yes	Yes	No
B	No	No	No	Yes
C	No	No	No	No
D	No	No	No	No

*Yes indicates statistically significant difference in means at the 95% confidence level

The number of statistically significant wage differences between attainment and non-attainment counties in category A provides fairly convincing evidence that the presence of ozone is not a sufficient disamenity to restrain growth in the service sectors; service industries will not *prima facie* be more likely to grow faster in attainment counties. Again, it is clear that the transition to a service economy is happening *faster* in nonattainment counties. The well-supported urban economics theory positing that industrial composition shifts towards those industries with greater localization economies as city size increases (Henderson 1988; Moomaw 1981) was reflected in this data. With the robust growth rates of *PSOTH* and *PSFIN* one could conclude that we are seeing evidence of localization economies as these service sectors are typically highly specialized. This seems intuitively logical but needs more investigation to be confirmed.

5.3.3 Geospatial Trends

By deconstructing the data to control for the effects of regional and urbanization trends it is possible to identify other factors which may affect the county's ability to attain the ozone standard and determine if, in some instances, the attainment regulations may be a partial driver of the transformative process. In most cases non-attainment counties were also those which made the transition to a service-led economy *faster* than their non-attainment counterparts and hence experienced stronger economic performance. From this analysis it is impossible to determine if the regulations contributed to the rate at which the manufacturing sector was replaced by the services sector but Kahn (2000b) alludes to the possibility that displacement effects may be a significant bi-product of regulations, "Future research might explore whether an unintended consequence of Clean Air Act regulation is to encourage economic development in highly polluted areas" (Kahn 200b, p. 580). When the data is deconstructed in other ways there appears to be very little difference in the performance of attainment and non-attainment counties. This could be an indication that there are location-specific characteristics which make it more difficult for some counties to attain the standard. It is also possible that differences in the relationship between economic performance and attainment of the ozone standard can be explained primarily by broader geographic trends.

Following Rappaport (2003) the regional, metropolitan and suburban trends are removed from the data using an accounting framework. Applying this decomposition framework divides the differences in average sectoral representation of shares into by geography, highlighting where there are geographic differences in average mean values. The accounting framework is outlined as follows:

$$\begin{gathered} \textit{Sector Mean Value} = \textit{National factor} + \textit{Regional factor} + \\ \textit{Metro factor} + \textit{New Metro factor} \end{gathered} \tag{5.1}$$

The national and regional factors capture broad trends. The national data is shown above Tables 5.1 and 5.2 and the regional data is segmented according to the regional variables outlined in Chapter 3. For the sake of simplicity, the data is divided into *MFG* and *Services* where *Services* is simply the sum of the sectoral shares of *ACS, PSOTH* and *PSFIN*. The regional factor is the regional values minus the national average values. Results are shown in Figures 5.21 and 5.22 for attainment and non-attainment counties, respectively. For quick interpretation, a negative value is an indication that the national average is greater than the regional value.

Of obvious immediate note is that the values for the Western U.S. states are negative in both attainment and non-attainment counties indicating less than average manufacturing in the West. The share of manufacturing in Southwestern states is greater than the national average in non-attainment counties but less than the average in attainment counties. That this result persists in all time periods indicates that where there is manufacturing in the Southwest, it is more than likely to be located in a nonattainment county. For the service sector, the story is much different. The

Southwest and Southeast have less than average levels of services in non-attainment areas and approximately average levels in attainment areas. At the same time the regional mean for the Northeast is greater in attainment areas providing some evidence that this broader class of services (to include *ACS*) locates in attainment areas.

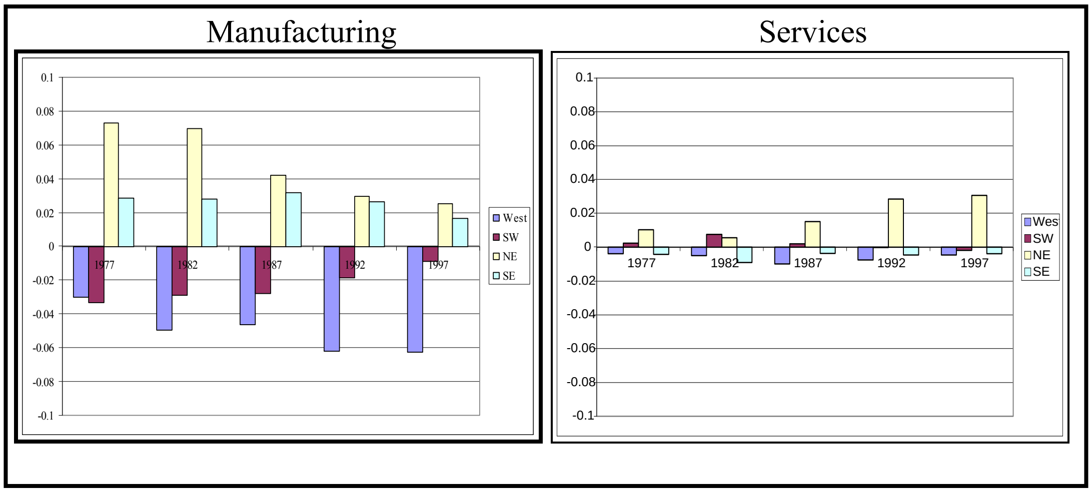


Figure 5.21 Regional factor of Manufacturing and Services in Attainment areas

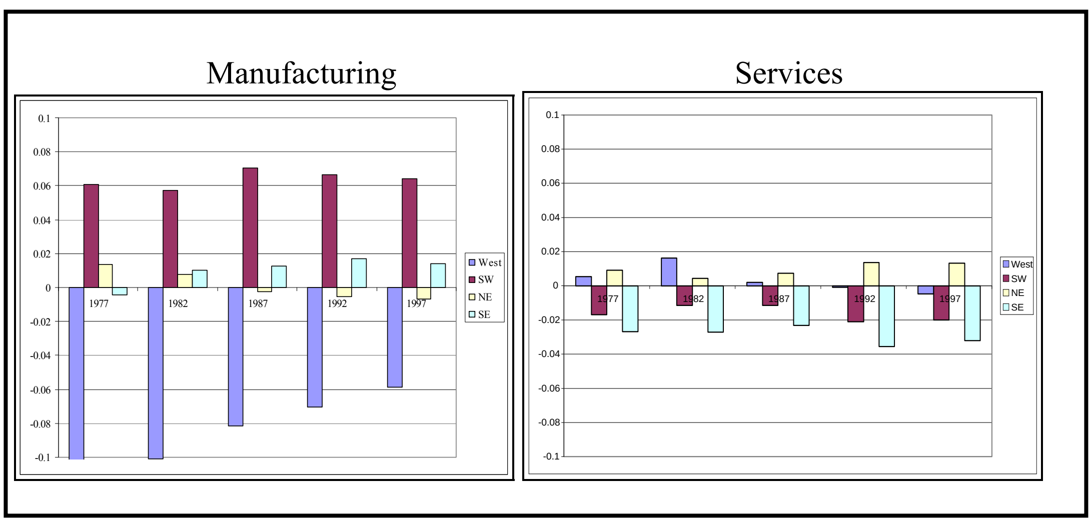


Figure 5.22 Regional factor of Manufacturing and Services in Non-Attainment Areas

Figures 5.23 and 5.24 show the results of calculating the metropolitan factor use the same framework. The metropolitan factor captures the differences between means of metropolitan and regional averages for manufacturing and services for that given category of attainment status. For example, a negative value in a non-attainment category indicates the regional mean for non-attainment counties is greater than the metropolitan mean for non-attainment counties in that region. The most striking result is that the mean value for manufacturing in Southwest metropolitan areas is significantly greater than the regional mean in attainment areas while almost equal to the mean in non-attainment areas. Perhaps more interesting is that the difference between the regional *versus* metropolitan average for manufacturing metropolitan in attainment counties continues to increase. This is an indication that the proportion of metropolitan manufacturing in "clean" areas continues to decrease relative to the rest of the region.

The results for the service sectors tells an entirely different, but expected story. In all regions, the metropolitan factor is greater than the regional factor in attainment areas. This is evidence of at least urbanization economies, firms in the services industry prefer to be locate in metropolitan areas to avail themselves of either the labor market or the positive externalities from locating near other firms. The invariant results for the non-attainment areas is intuitive. Most non-attainment areas are located in metropolitan areas so it is intuitive that the regional and metropolitan averages will be very similar.

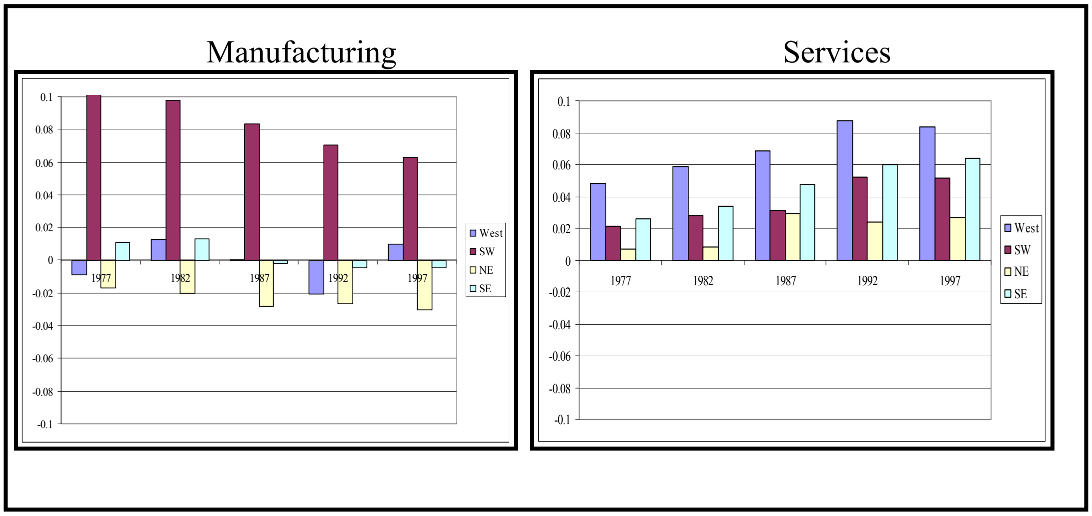


Figure 5.23 Metro factor of Manufacturing and Services in Attainment areas

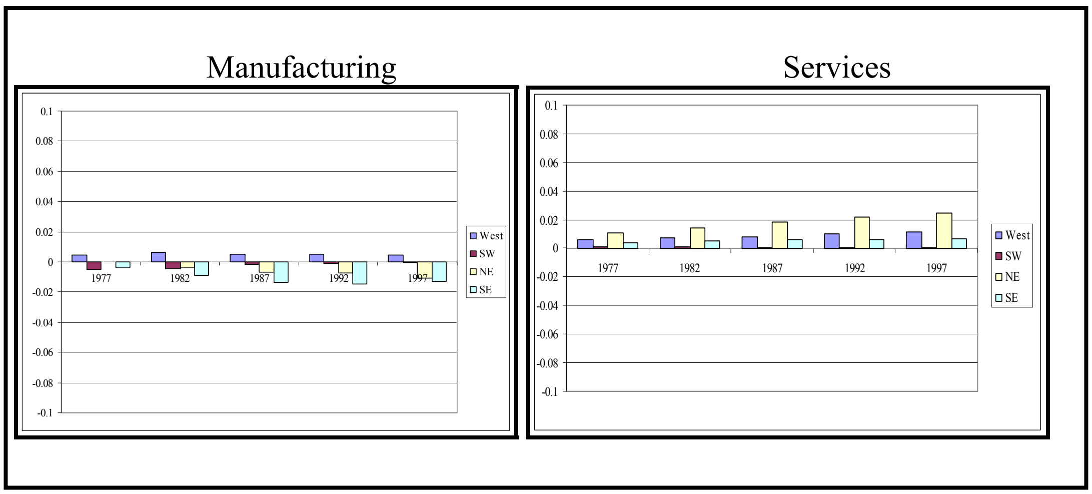


Figure 5.24 Metro factor of Manufacturing and Services in Attainment areas

The suburbanization trend is illustrated in Figures 5.25 and 5.26 where the new metropolitan (*e.g.* suburban factor as captured by category D) mean was subtracted from the overall metropolitan mean. The services sector is surprising and very interesting in the context of this analysis. There appears to be no regional differences in the results. While it is not surprising that the mean level of representation of services in category D counties is lower than the metropolitan mean, that this relationship is relatively homogenous across the country and across attainment classifications is surprising. This is clearly an indication of the strong urbanization economies in the services sector, irrespective of other socioeconomic or geographic trends.

Finally, the plots from the manufacturing sector show an interesting trend. In Figure 5.25 the Southeast is the only region where the suburban mean value for manufacturing is greater than the overall metropolitan mean, indicating a substantial presence of manufacturing in these counties. This difference is even greater in non-attainment areas (Figure 5.26). The time trend in non-attainment areas is instructive; in 1987 the new metropolitan area mean exceeds the metropolitan mean in all regions except the West. Recall that these counties became metropolitan in 1990 or later so this is an indication that the spread of manufacturing, not services, into less-densely populated areas drove the population expansion. It is useful to ponder why the trend is so predominant in non-attainment areas but less pronounced in attainment counties.

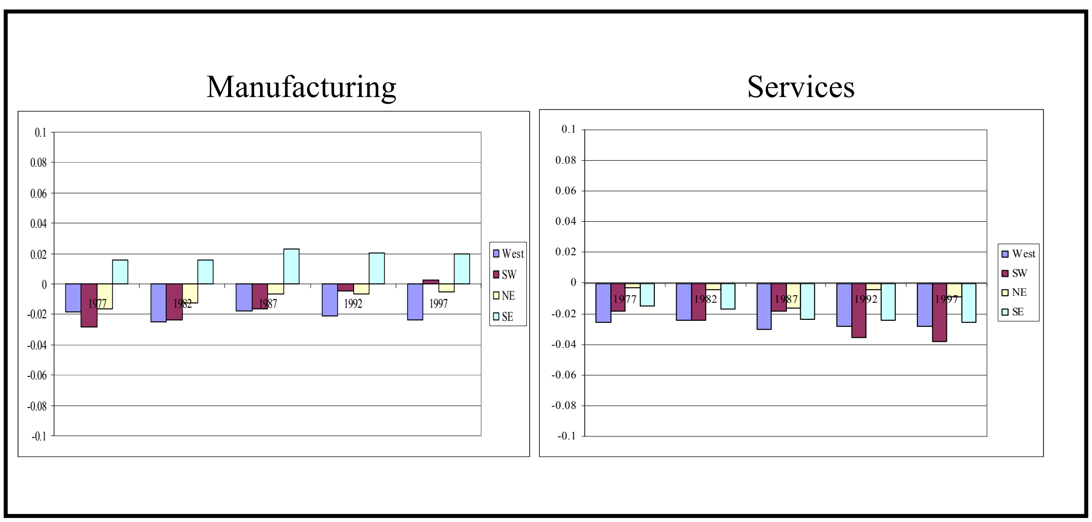


Figure 5.25 New Metro factor of Manufacturing and Services in Attainment areas

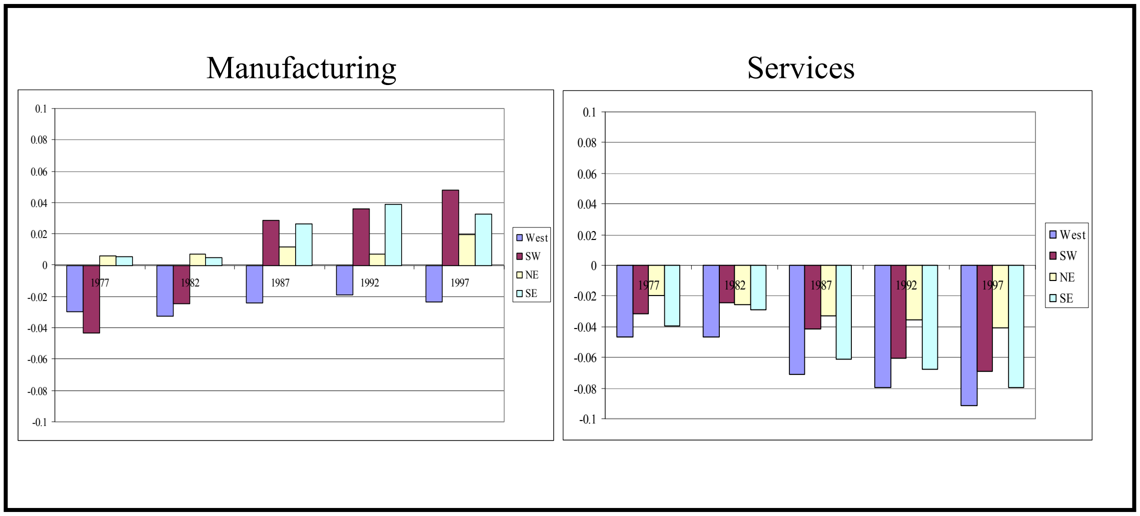


Figure 5.26 New Metro factor of Manufacturing and Services in Non-Attainment areas

5.4 Conclusion

Taken as a whole, this analysis reveals trends that explain why ozone pollution may persist. First, there is no dispute that motorized vehicle travel is expected to increase consistently for the foreseeable future. Policy efforts are focused on reducing emissions per mile rather than reducing the number of miles traveled. Achieving the dramatic reductions necessary to ensure that increases in VMT do not worsen the ozone problem depends primarily on implementation of new rules regulating emissions standards for light and heavy trucks. Predicting adoption rates of new standards is outside of the scope of this inquiry but history suggests that conservative estimates are prudent.

Emissions from point sources decreased dramatically in spite of an increase in facilities producing NOx and VOCs. Emissions estimates are only available through 2001 (the first year the 8-hour standard was implemented) but further reductions have inevitably occurred yet hundreds of counties still fail to attain the standard. If the political and legal challenges of implementing the 8-hour standard (proposed in 1997 and finally accepted in 2001) can be used as a benchmark it is likely that that incremental emission reductions from this point forward will come only after considerable deliberation.

The lifecycle curves tell a very clear story, the transition to a service-based economy is happening quicker in non-attainment areas, and fastest overall in the oldest metropolitan counties. The service sectors are not growing faster in attainment areas as might be expected. A literal interpretation of this is probably not correct – that service sectors thrive in areas where the ozone quality is dirtiest. This is too simplistic and ignores the other economic factors that could lead to this relationship. Most likely part of the variation can be explained by the presence of scale economies. Another contributing explanation could be that that other amenities are available in non-attainment counties that *ceteris paribus* would seem less desirable because of their high ozone levels. As service industries depend on human capital rather than capital or transport cost, firms will locate where they can attract the best people and/or where they can benefit from scale economies. Therefore the next step to understanding the close relationship between services and non-attainment status entails investigating trends that continue to drive the relationship from the demand-side.

CHAPTER 6

PERSISTENCE OF OZONE: TRENDS ON THE DEMAND SIDE

6.1 Introduction

The transition to a service-based economy is purported to bring many benefits; a service-based economy is associated with post-industrial development and introduces more white-collar jobs, higher incomes and less pollution as traditional smoke-stack industries are gradually replaced by information technology and service industries as the driver of economic growth. A large body of research on the Environmental Kuznets Curve posits that higher incomes also lead to a reduction in pollution as demand for a cleaner environment becomes a more important factor in the overall growth imperative of an economy. However, the perplexing aspect of tropospheric ozone is that, on average, the counties that failed to attain the ozone standard actually fared better in a number of different economic categories than those that did not *and* over time these counties also derived larger proportions of their county wage bill from the service sectors. Conceptually, it is plausible that this is simply an indication that citizens in the U.S. have not yet reached the inflection point at the top of the hypothetical Kuznets Curve. Yet we know ozone air quality has improved across the country, indicating that the U.S. has passed the inflection point on the EKC. This chapter begins to disentangle the drivers of the ozone problem from the perspective of consumers who may or may not demand reductions in ozone levels.

A key indicator that the ozone problem is both complex and likely to persist is the prevalence of producer services in areas with high levels of ozone. Producer services is a sector typically associated with high levels of human capital and that population demands quality-of-life offerings (Clark *et al.,* 2002; Glaeser 2001; Glaeser and Shapiro 2003). Typical amenities cited in the literature are access to good education systems, cultural amenities such as concerts, museums and art galleries, access to recreational facilities and a pleasant aesthetic environment. It is this latter factor that is of interest to this study. The producer services sector, unlike manufacturing, is strongly positively correlated with the natural amenities scale *AMEN* (introduced in Chapter 3). Recall that *AMEN* rates desirability of natural elements such as climate, typography and the presence of water. The correlations indicate that high levels of income (and human capital) are associated with a "nice place to live." The tolerance for a persistent ozone problem seems contradictory. It is unreasonable to assume a causal relationship, *e.g.,* that people actually prefer to live in areas of high ozone. This chapter shows statistical evidence that explains the contradictory initial findings and finds evidence that ozone is not a strong enough disamenity to drive ozone levels to zero, as would be predicted by the EKC (see Figure 1.1).

6.2 Descriptive Statistics

Descriptive statistics for population, density, income and wages are shown in Tables 6.1 and 6.2. The counties naturally rank themselves in terms of wages, income and population by the duration that each county has been metropolitan, with the lowest wages and income in the non-metropolitan counties. This is not surprising given that the oldest metropolitan areas are the most established. This is consistent with the established urban theory that income grows with population (Barro 1991; Glaeser 1992). Surprisingly, the coefficient of variation for all counties for wages *(WPW)* and *(PCPI)* is bounded between 0.130 and 0.235. This indicates counties are relatively homogenous within metropolitan age categories in terms of wages and income.

The mean population size of the oldest metropolitan areas Category A is significantly higher (over four times) than those counties that became metropolitan in the 1970s, Category B. Both population and population density decline as the age of the metropolitan area decreases. The natural ranking of counties presented in Chapter 5 according to the date the county became metropolitan is seen in the data. This ranking both in population density is a proxy for the built environment since cities that are more densely populated must necessarily have different types of infrastructure and architecture. Dense areas often have more high rise buildings and are more likely to have effective public transportation systems than less dense areas, characterized by strip malls and wide roads built for each of vehicle travel.

The rate of growth over the two decades is illustrative. Population doubled in Categories C and D counties while population increased by only about 20% in Category A counties. This is consistent with Census 2000 findings that younger cities grew faster than older cities (Glaeser 2001) and may be an indication of "space-filling" phenomenon such that people move where space is plentiful and, by extension, land rents are cheap.

The newest counties' mean population density was exactly ten times less than the old metropolitan areas. For establishment density, the disparity between new and older metropolitan was even more pronounced with a forty-fold difference. This finding reflects metropolitan growth patterns where newly urbanized areas tend to be characterized by low density, sprawling growth while older cities tend to be denser; having been developed in an era of higher relative transportation costs (Henderson and Mitra 1993; Jacobs 1969). Many of the new metropolitan counties are adjacent to older metropolitan areas and have absorbed much of the growth in US population. Not surprisingly the non-metropolitan counties experienced only modest growth in terms of population and population density.

Table 6.1 Descriptive statistics for economic and density variables for A, B and C county categories, 1977, 1987 and 1997

	A (Oldest Metro) n=347			**B** (Metro in 1970) n=105			**C** (Metro in 1980) n=255		
	1977	**1987**	**1997**	**1977**	**1987**	**1997**	**1977**	**1987**	**1997**
Population Density									
Mean	1.351	1.389	1.429	0.216	0.245	0.29	0.177	0.197	0.226
Std. Dev	4.676	4.696	4.750	0.383	0.403	0.750	0.413	0.399	0.407
Min	0.015	0.019	0.019	0.028	0.034	0.042	0.012	0.012	0.012
Max	63.707	65.011	67.639	2.655	2.735	3.453	3.765	3.559	3.458
COV	3.462	3.380	3.325	1.775	1.642	2.544	2.336	2.027	1.804
Population (thousands)									
Mean	391.795	429.199	469.309	86.081	103.884	127.218	71.222	85.852	102.593
Std. Dev	597.389	659.582	707.680	67.948	88.188	108.238	80.427	106.304	132.498
Min	8.726	10.100	11.499	6.524	7.100	8.973	4.190	5.080	6.150
Max	7251.640	8553.840	9126.130	478.700	632.060	722.16	769.670	1192.200	1609.220
COV	1.525	1.537	1.508	0.789	0.849	0.851	1.129	1.238	1.291
Wage Per Worker									
Mean	20139.33	23717.44	26364.30	17671.49	20089.61	22257.10	16522.89	19371.88	21150.33
Std. Dev	2787.19	3571.95	5253.38	2670.22	3397.57	3378.14	3153.37	3487.90	3958.24
Min	13708.67	14983.74	16844.54	11558.65	14581.51	15060.50	9284.17	10942.50	12614.98
Max	30006.06	41950.93	59061.68	26384.66	29724.30	31066.69	28330.32	31369.10	44796.35
COV	0.138	0.151	0.199	0.151	0.169	0.152	0.191	0.180	0.187
Per Capita Personal Income									
Mean	12635.48	18202.52	22631.09	11447.61	16357.00	20360.44	10738.64	15588.09	19309.72
Std. Dev	2158.58	3897.60	5414.26	1744.68	2778.31	3595.54	1709.81	2868.85	3686.01
Min	6345.08	8008.18	11346.85	6726.26	84158.27	10590.96	6400.74	6054.94	12451.48
Max	23766.23	38606.17	57866.35	15297.69	24487.68	32474.65	17444.76	29264.95	40511.94
COV	0.171	0.214	0.239	0.152	0.170	0.177	0.159	0.184	0.191
Establishment Density									
Mean	553.025	692.767	748.860	51.742	73.753	114.29	53.772	75.865	94.218
Std. Dev	3809.290	4622.720	4438.410	115.190	161.411	243.244	207.383	292.487	316.890
Min	2.167	0.452	0.078	1.862	2.224	5.149	0.255	1.004	2.432
Max	69655.970	84667.620	80949.850	850.337	1363.290	1812.17	2103.010	2839.360	2862.160
COV	6.888	6.673	5.927	2.226	2.189	2.128	3.857	3.855	3.363

Table 6.2 Descriptive statistics for economic and density variables for D, E and F county categories, 1977, 1987 and 1997

	D n=107			**E** n=2207			**F** n=75		
	1977	**1987**	**1997**	**1977**	**1987**	**1997**	**1977**	**1987**	**1997**
Population Density									
Mean	0.110	0.123	0.140	0.041	0.042	0.0448301	0.094	0.099	0.108
Std. Dev	0.229	0.236	0.239	0.122	0.126	0.1369761	0.165	0.159	0.158
Min	0.000	0.001	0.001	0.000	0.000	0.0001673	0.003	0.004	0.004
Max	2.059	2.089	2.114	2.424	2.661	3.0312376	1.086	0.993	0.978
COV	2.074	1.918	1.713	2.983	2.988	3.055	1.765	1.607	1.465
Population (thousands)									
Mean	49.538	58.694	70.453	20.547	21.501	22.965545	48.040	52.392	58.925
Std. Dev	37.588	47.009	56.319	18.484	19.564	21.605994	74.047	76.733	85.274
Min	3.620	5.100	5.440	0.090	0.090	0.11	1.990	3.050	3.980
Max	168.790	260.780	318.440	161.650	161.870	166.92	534.960	471.840	540.000
COV	0.759	0.801	0.799	0.900	0.910	0.941	1.541	1.465	1.447
Per Capital Personal Income									
Mean	10592.79	14915.59	18401.97	9694.01	13277.77	16252.42	10322.19	14440.18	17691.94
Std. Dev	1844.28	2881.99	3502.72	1967.43	2538.00	3046.25	1887.16	2553.59	2844.36
Min	7340.19	10014.37	13490.81	3840.45	4646.84	3343.07	6147.75	9236.21	12335.50
Max	17029.85	28221.51	36001.55	19787.56	29938.10	46109.78	14985.66	23422.13	26259.23
COV	0.174	0.193	0.190	0.203	0.191	0.187	0.183	0.177	0.161
Wage Per Worker									
Mean	16158.53	18574.14	20334.56	14930.61	17046.91	17846.14	15831.04	18203.61	19828.85
Std. Dev	3594.45	4327.57	4213.29	3481.07	3712.21	3927.73	3327.12	4269.34	4431.55
Min	8978.60	7459.21	11279.83	3879.24	4697.69	2427.49	8241.86	9350.08	10980.54
Max	28681.14	36006.87	38969.24	35090.76	38467.12	45126.89	25863.48	28858.88	35579.32
COV	0.222	0.233	0.207	0.233	0.218	0.220	0.210	0.235	0.223
Establishment Density									
Mean	31.91	43.53	50.97	12.30	14.84	19.43	19.81	24.08	29.85
Std. Dev	108.42	133.14	129.02	86.39	105.24	132.86	46.20	48.88	53.93
Min	0.09	0.13	0.27	0.00	0.00	0.01	0.35	0.33	0.79
Max	872.05	929.11	941.84	2281.05	2260.79	3736.88	354.25	295.31	353.52
COV	3.397	3.059	2.531	7.023	7.094	6.838	2.332	2.030	1.807

Descriptive statistics for the natural amenity scale that describes the desirability of the natural environment are shown in Table 6.3. A high amenity value indicates desirability of the metropolitan county. The mean value of *WATER* of 7.86 indicates 7.86% of the total area of the county is water. The mean value for hours of sunlight in winter for the month of January is 146.65 or an average of 4.8 hours per day. *TYPO* is a "1" to "21" ordered variable representing gradients of the typography with "1" and "21" indicating flat plains and high mountains, respectively

Table 6.3 Descriptive Statistics for Amenity variables

	AMENITY	*WATER*	*TYPOGRAPHY*	*SUN*	*SUMMER TEMP*	*WINTER TEMP*
Mean	3.48	7.86	7.88	146.65	76.15	34.76
Std. Dev	1.01	14.72	6.25	31.57	4.72	11.34
Min	1.00	0.00	1.00	48.00	58.50	3.50
Max	7.00	75.00	21.00	260.00	91.20	66.80
No.	831	831	831	831	831	831

6.3 Natural Amenity Preference

The cities that grew fastest in the 1990s had warm, dry climates, strong human capital bases and infrastructure that encouraged private vehicle travel rather than public transportation (Glaeser and Shapiro 2003). Not coincidentally, warm climates and reliance on motor vehicle travel exacerbates ozone problems. The human capital pool attracted to such areas also value natural amenities such as a nice landscape, proximity to water or other recreational opportunities and a climate conducive to interaction with the natural world. While education and cultural amenities might be intuitively associated with higher levels of human capital, there is no reason to believe that people working in producer services would value natural amenities any more than a person working in the manufacturing sector, for example. Yet the results from Table 6.4 are striking. The table presents the correlation matrix of the *AMEN* variable, *WATER,* and a rating of typography *TYPO* (where low values are the least desirable and high numbers are the most desirable), and the sectoral shares.

Table 6.4 Correlation coefficients for amenities and sectoral shares

	AMEN	*WATER*	*TYPO*	*PSFIN*	*PSOTH*	*ACS*	*MFG*
AMEN	1.00	0.31	0.36	0.14	0.24	0.11	-0.31
WATER	0.31	1.00	-0.19	0.14	0.14	0.19	-0.09
TYPO	0.36	-0.19	1.00	-0.01	0.02	0.06	-0.01
PSFIN	0.14	0.15	-0.01	1.00	0.55	0.29	-0.35
PSOTH	0.24	0.14	0.03	0.55	1.00	0.21	-0.35
ACS	0.11	0.20	0.06	0.29	0.21	1.00	-0.25
MFG	-0.31	-0.09	-0.01	-0.35	-0.37	-0.25	1.00

Recall that the *AMEN* variable is a composite of natural amenities, including water, typography and climate. The table above shows clear evidence that the service industries are located in areas deemed as a "nice place to be." Firms in the service sectors depend on labor, rather than access to natural resources or transportation routes so the high correlation between the services shares above and the *AMEN* variable can be interpreted as an indication of demand. However, the negative correlation between *MFG* and the amenities variables cannot be interpreted as an absence of demand for natural amenities by workers in the manufacturing sector because location decisions of manufacturing plants is a function of many other considerations.

The values of the correlation coefficients of the service sectors with the *AMEN* variables are intuitive. *PSOTH* is the most strongly correlated with a coefficient of 0.24 indicating this is the sector with the highest demand for natural amenities. The smaller correlation coefficient for *PSFIN* of 0.14 is not surprising given that the financial services sector may be more sensitive to urbanization economies and are more likely to base location decisions on proximity to financial markets rather than worker demand. *ACS* has the lowest coefficient, 0.11, of all the service sectors. The sector encompasses a broad range of consumer services and may either require a less advanced set of skills (such as a call center) or necessarily be located near to consumers (such as health care). Hence it is likely that location of *ACS* firms will be less likely to be driven by worker demand than *PSOTH* or *PSFIN.*

6.4 Trends – Clustering of Services

The transformation to a service economy affects the demand for density and changes the locational decisions of both producers and consumers in metropolitan areas. The use of information technologies and the itinerant characteristics of some service industries has begun to decouple the need for physical proximity between producers and consumers and changed the distribution of certain sectors across metropolitan areas, pushing the service sector industries to less dense areas (Phelps 2001). The density measures presented in Tables 6.1 and 6.2 are consistent with this fact. These measures only describe the spread of sectors across space and do not illustrate the tendency of maintain proximity to other producers in the same sector or, in other words, their tendency to "cluster."

There is considerable research on why firms in certain sectors might cluster, or group together to avail themselves of the intangible benefits from physical proximity, commonly known as externalities (Sabel 1989; Saxsenian 1994) but we know very little about how clustering generalizes across time and space (Malmberg and Maskell 2001). The reasons for this are two-fold. First while it is relatively easy to capture changes in sectoral composition of a county across time by simply taking a snapshot of economic data at specified time periods, it is more difficult to determine how firms within these sectors act in relation to other firms. This is because data on the financial performance of firms is often proprietary. Second, the methods for identifying clustering behavior are not well developed.

It seems *a priori* reasonable to assume to assume that the clustering behavior of certain sectors would be so dissimilar from each other that differences across a broad (in this case, national) scale would be evident. The results presented below indicate this was not an unreasonable assumption. Using manufacturing as a baseline this section shows how three different types of service industries cluster spatially and illustrates how clustering behavior can change over time.[9] In brief, the manufacturing sector exhibited significant clustering behavior in the first time period considered here, 1977, but became less concentrated by the final time period, 1997. By contrast, the financial services and business services sectors displayed increased clustering over the same period. A similar outcome was expected for the consumer services sector but surprisingly there was much less evidence of clustering in this sector. Possible explanations are discussed later.

Henderson (1988) states that firms will agglomerate to the point where the benefits of agglomeration are outweighed by explicit or implicit costs of operating within such a location. After such threshold point is reached clustering behavior cannot be expected. Using empirical evidence over the 1977-1997 time-period showing how manufacturing and producer services scale differently with population in the five categories of counties defined in Chapter 3; and recall from Figure 3.4 the county categories represent the age in which the county became metropolitan which conveniently, is also a proxy for population density. Understanding the relationship between population scale, density and sectoral performance begins to answer the question of how intermediate locations fit into agglomeration theory and allows us to move beyond the traditional means of scaling up the level of analysis to describe the

[9] The manufacturing sector provides a good baseline against which to test the clustering results because most economic analyses to date focus on clustering behavior of manufacturing firms.

existence of clusters.[10] The analysis naturally leads to asking whether sectoral growth rates also cluster; for example are counties experiencing high proportional growth rates of sector A are more or less likely to be located next to another county with similar growth rates of sector A?

The statistical results show that overall, there is less evidence of agglomeration in the goods production sector and advanced consumer services than in financial services and other producer services. Acknowledging the birds-eye view from which this analysis is constructed is not the typical vantage point to examine clustering tendencies. Nevertheless, there are benefits to analyzing data at the county level, rather than the firm level. The primary advantage is the data coverage and availability. This makes it possible to understand *differences* across time and sectors. In the U.S. access to firm level data is restricted[11] making it difficult to identify changes across time but even more difficult to understand differences across sectors. Using a representational analysis such as the sectoral shares variables is admittedly a coarse measure of firms, but there is still much to be learned from this existing publicly-available data. Careful empirical work at the county level can reveal interesting characteristics of sectors and perhaps more importantly, provides a glimpse into the dynamics of relationship between the sectors and the populations and geographies in which they function.

Partial correlation coefficients show how the sectoral shares, income and density change in relation to each other and illustrate how the results may differ based on county attainment status. The partial correlation coefficients show the correlation

[10] Contemporary efforts to explain agglomeration often simply up-scale the spatial context for the agglomeration *e.g.*, polycentricity, metaclustering and regionalization are all efforts to explain agglomeration by using locational patterns to explain geographical instances of increasing returns (Phelps 2004).

[11] Firm level data is available at the Center for Economic Studies in the Bureau of Economic Analysis, U.S. Census Bureau and only available to non-Bureau members who have been deputized and pay a substantial fee.

of each variable in relation to a target variable, while all other variables are held constant. The coefficients for *PSOTH, PSFIN, MFG* and *ACS* are shown in Tables 6.5 – 6.8, respectively (partial correlation coefficients were also calculated using five year sectoral growth rates but since very few of the results were significant at the 5% level, (the results are not reported here but are available upon request).

As expected, there is a positive and significant relationship between *PCPI* and the producer services sector (*PSOTH)* and manufacturing (*MFG),* while the results are negative for advanced consumer services with the exception of 1977 in ozone attainment areas, where the coefficient is positive and significant. Also not surprising, *MFG* is negatively associated with every other sectoral share measure, again with the exception of ozone counties in 1977. Unexpectedly, there is a difference in signs for correlation coefficients of population density, *POPDENS* with *PSOTH* and *PSFIN.* It is expected that *PSFIN* will have a positive (but not always significant) coefficient, the negative coefficients for *PSOTH* are surprising. It is clear that in non-attainment counties *PSOTH* are associated with lower levels of *POPDENS*, except for non-attainment counties in 1997. The results are mirrored by the partial correlation results for *MFG* and *POPDENS*, with a positive coefficient only in attainment counties in 1997. Tables 6.5 and 6.7 are also interesting. The relatively strong negative correlation between *MFG* and *PSOTH* is not surprising but it is interesting that in non-attainment counties in both 1977 and 1997 *PSOTH* was negatively correlated with both *MFG* and *POPDENS* and that the negative relationships became stronger, not weaker, over the twenty-year period.

Table 6.5 Partial correlations for Producer Services Other, *PSOTH*, 1977 and 1997

Variable	*OZONE*	*PCPI*	*PSFIN*	*ACS*	*MFG*	*POPDENS*
1977	Attainment	0.239*	0.218*	0.228*	-0.323*	-0.010
	Non-Attainment	0.570*	0.277*	0.077	-0.309*	-0.148*
1997	Attainment	0.415*	0.138*	0.088*	-0.327	0.170*
	Non-attainment	0.711*	0.144*	-0.060	-0.428*	-0.310*

*Indicates significance at the 5% level

Table 6.6 Partial correlations for Producer Services Financial, *PSFIN*, 1977 and 1997

Variable	*OZONE*	*PCPI*	*PSOTH*	*ACS*	*MFG*	*POPDENS*
1977	Attainment	0.144*	0.218*	0.318*	-0.229*	0.160*
	Non-Attainment	0.136	0.277*	0.231*	-0.128	0.428
1997	Attainment	0.403*	0.138*	0.191*	-0.260*	0.082*
	Non-attainment	0.255*	0.144*	0.053	-0.121	0.377*

*Indicates significance at the 5% level

Table 6.7 Partial correlations for Manufacturing, *MFG*, 1977 and 1997

Variable	*OZONE*	*PCPI*	*PSFIN*	*ACS*	*PSOTH*	*POPDENS*
1977	Attainment	0.216*	-0.230*	0.046	-0.323*	-0.120*
	Non-Attainment	0.155*	-0.128	-0.027	-0.309*	-0.004
1997	Attainment	0.252*	-0.260*	-0.134*	-0.327*	0.087*
	Non-attainment	0.290*	-0.121	-0.122	-0.430*	-0.151*

*Indicates significance at the 5% level

Table 6.8 Partial correlations for Advanced Consumer Services, *ACS,* 1977 and 1997

Variable	*OZONE*	*PCPI*	*PSFIN*	*PSOTH*	*MFG*	*POPDENS*
1977	Attainment	0.151*	0.320*	0.203*	0.046	0.022
	Non-Attainment	-0.120	0.231*	0.077	-0.030	0.138
1997	Attainment	-0.050	0.191*	0.088*	-0.134*	0.056
	Non-attainment	-0.083	0.053	-0.060	-0.122	0.192*

*Indicates significance at the 5% level

The data in Table 6.5 shows that the relationship between *PSOTH* and population density is negative in non-attainment counties. It could easily be assumed that *PSOTH* strong association with Category A (typically counties which are more dense) counties would be simply a function of density and all of the agglomeration benefits which accrue to businesses in densely population areas. Yet once density is controlled for a strong difference between attainment and non-attainment counties emerges.

A new technique sheds some light on how we might predict these trends to develop in the future. The positive relationship between services and ozone levels will continue if producer services disperse geographically, as manufacturing has done. Dispersion would decrease the density of activity and conceivably go some way to alleviating the ozone problem. Tests for spatial clustering are relatively new in the economics literature but introduced here as a promising approach for future work. Two tests for spatial randomness evaluate how counties with positive growth rates in each of the sectors interact, or fail to interact with neighboring counties spatially. The spatial randomness tests use the county sectoral data which has been geo-coded according to its county centroid. The tests use the distance to the nearest neighbor for each county to calculate a distribution function. Two different test statistics, the F test (Holgate 1965a; Cressie 1993; Kaluzny *et al.* 1998) and the G (Holgate 1965a; Cressie 1993; Kaluzny *et.al,* 1998) test are used to test for spatial regularity (randomness) or spatial clustering. While there are many tests for spatial randomness, these two tests are relatively simple to execute and interpret and also the least sensitive to edge-effects in the case of large *n* (Cressie 1993). Details of the methodology and results are found in Appendix D and only the conclusions are presented here.

Figures 6.1 And 6.2 show the distribution functions for *ACS* showing the relationship between the tendency to cluster, represented by $\widehat{G}$ as a function of distance. The interpretation of the graphs is that in counties with high growth rates of *ACS* (defined as greater than 50% over the five-year period) there is less of a tendency to cluster in the 1992-1997 time-period than there was in the 1977-1982 time period.

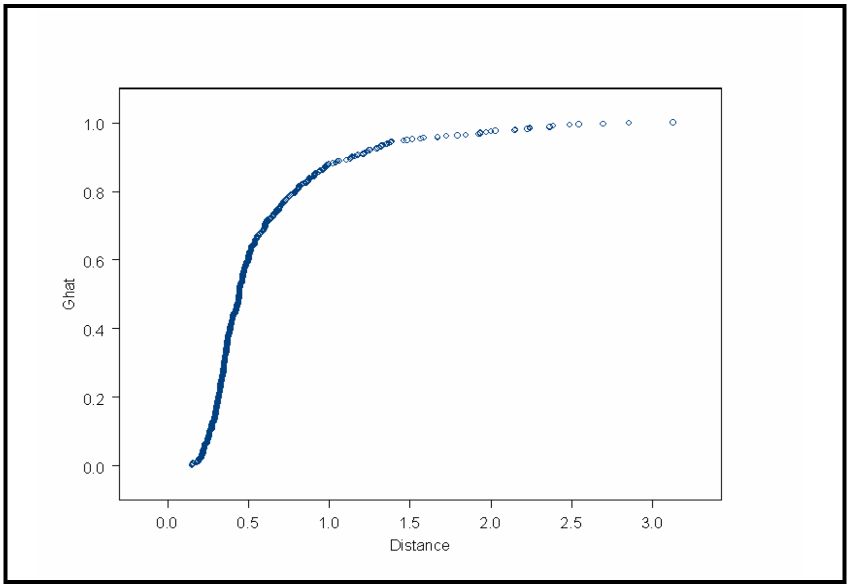


Figure 6.1 Distribution function for *ACS* Growth > 50%, 1977-1982

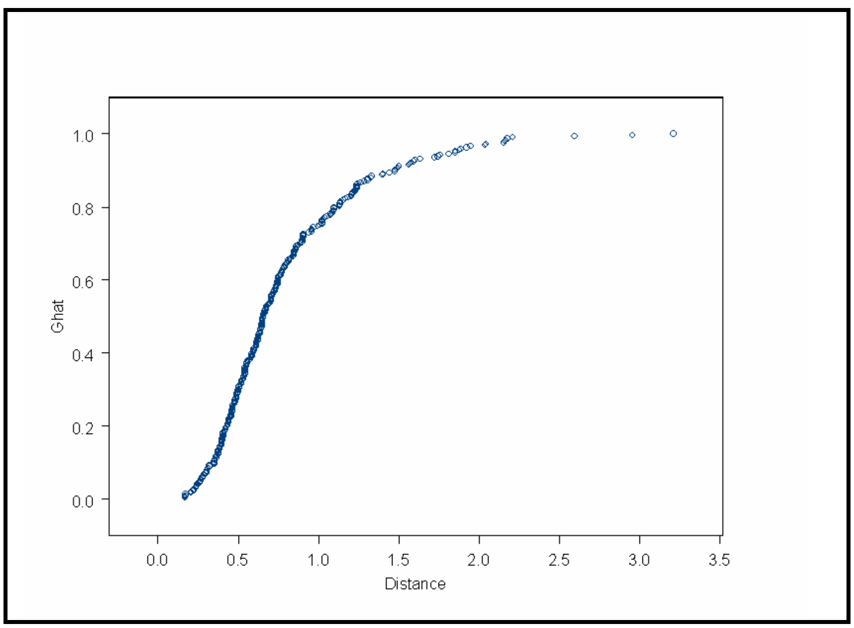


Figure 6.2 Distribution function for *ACS* Growth > 50%, 1992-1997

To a lesser extent, counties with high levels of growth in producer services also trended towards more spatial regularity in the 1992-1997 growth period with the values decreasing from 0.57 to 0.37 at a distance of 0.5. In spite of the decrease this sector shows the most evidence of clustering among the four sectors in the latter period. The financial services sector did not show strong evidence of clustering in the early time period but by 1992-1997 financial producer services exhibited more spatial clustering than advanced consumer services and manufacturing but slightly less than producer services. The values for goods production sector remained relatively constant over the two time periods.

These analyses point a new direction in analysis of clustering and while preliminary, show some evidence that some services are concentrating. If this is the case, and that these sectors are associated with the presence of ozone, then we can expect ozone high levels of ozone to persist without active intervention. Such interventions might include incentives or regulations for implementation technological fixes that will reduce emissions per unit. Examples are continued improvements in vehicle efficiency and capping mechanisms at fuel pumps. Other options are encouraging behavioral change to reduce activity that emits pollutant such as encouraging carpooling or telecommuting.

CHAPTER 7

ASSESSING OZONE: IS IT A DISAMENITY?

7.1 The Absence of Ozone as an Amenity

The differences between counties with an ozone problem and those that do not are marked. The question remains, to what extent is the absence of ozone valued over other amenities or benefits of urban life. If ozone is not perceived as a significant disamenity then it becomes less likely that people will not pay to avoid smog. I estimate hedonic regressions to ascertain the importance of both attainment regulations and the presence of ozone in the value of homes, arguably an indication of economic performance, and population growth, an indication of desirability of a county's location.

7.2 Descriptive Statistics

Descriptive statistics for variables used in the regression analysis but not presented in previous chapters are listed in Table 7.1. The variables reflect characteristics of the socioeconomic composition and the natural amenities in a county that will contribute to both housing prices and population growth. The variables *DETACHED* (% of homes in a county that are single-family houses), *OWNER* (% of homes in a county that are owner-occupied), *RETIREAGE* (% of residents that are over the age of 65) and *MINORITY* (% of residents that are non-white) are both determinants of housing values *(MEDVAL)* and a county's population growth *(POPGR)*.

Other variables that capture natural amenities are *TYPO, SUN, WINTER* and *WATER* (in logarithmic form). *SUMMER*, the average temperature in July, was too highly correlated with both dependent variables and was not used. *PSOTH* and *PSFIN* (both in logarithmic form for ease of interpretation) are proxies for levels of human capital because they rely on a highly skilled workforce.

Table 7.1 Descriptive statistics for regression variables

	DETACHED	*OWNER*	*RETIREAGE*	*MINORITY*	*LOGMEDVA*	*LOGPOP*
Mean	0.658	0.633	0.122	0.164	11.152	0.134
Std. Dev	0.115	0.090	0.035	0.170	0.409	0.143
Min	0.002	0.163	0.013	0.00	10.295	-0.256
Max	0.918	0.826	0.337	1.00	13.096	0.833
COV	0.175	0.142	0.29	1.036	0.036	1.067
No.	831	831	831	831	831	831

ACSSH is not a good proxy for human capital because of the wide variation of sectors included in this category.

Control variables *GEO* and *MSA* factor out regional and density effects in housing prices and population growth. *GEO* is a "1" to "3" variable representing three regions of the U.S. The fourth, the West is omitted to avoid a non-singular matrix. Likewise, *MSA* is a "1" to "3" variable where "1" is Category A metropolitan areas, "2" represents Category B metropolitan areas and "3" is Category C metropolitan. Category D is the omitted variable. Another control variable variable, Urban Influence Code, *UIC* represents a classification system defined by the U.S. Department of Agriculture (USDA) that accounts for the size of the metropolitan area and, when the county is non-metropolitan, represents the size of the nearest metropolitan area. As its name suggests, this variable expands the simple metropolitan/non-metropolitan dichotomy defined by the Census Bureau and captures the influence a large metropolitan area may have on a smaller counties in its proximity. A value of 1 represents counties with populations greater than 1 million people and a value of 9 represents a completely rural county with a population less than 20,000 people.

7.2 Model and Analysis

Following Kahn (2001a) two equations are estimated to ascertain the effect of air quality on housing prices and population growth in 1997. Equation (7.1) texts citizens' revealed preferences for certain county characteristics, including ambient ozone levels and the attainment variable in the specification of home prices.. To determine if ambient ozone levels help explain population growth (or decline) in metropolitan counties I estimate the population-growth model in Equation (6.2). The functional form is:

$$Log(MEDVAL)_j = \alpha + BX_j + \varepsilon_j, \tag{7.1}$$

$$Log(POPGR)_j = \alpha + BX_j + \varepsilon_j, \tag{7.2}$$

where X is a vector of air quality, sectoral composition and demographic attributes for metropolitan county j. Both Equation (7.1) and Equation (7.2) are estimated using two different variables for ozone, a predicted arithmetic mean (described below) and the attainment variable. The equations were also estimated controlling for spatially correlated error terms but did not yield results that significantly changed the conclusions and are therefore not reported here. Results are available upon request.

7.3 Estimation and Results

Equations (7.1) and (7.2) were estimated using SPlus with a correction for heteroscedastic error terms. The data used is from 1997 and so it is possible to use the enhanced attainment variable *ATMTEPA* with values ranging from 0 to 6 depending on the severity of the ozone problem, rather than the binary variable used in the previous chapters. As many of the predictor variables could conceivably be correlated, and result in biased estimates due to multicollinearity,I carefully checked the correlation matrix.

Consistent with results from previous chapters, a one-unit increase in the attainment variable is associated with a 6.7% increase in median house prices. While this seems considerable, relative to the results from other variables, it does not seem as significant. By comparison, a 10% increase in population growth raises the housing price by 45% while a 10% increase in the proportion of wages derived from the producer services sector is associated with a 23% increase in the median value of a house. Of the amenity variables the presence of water and sunlight are positive and significant determinants of housing values with a 10% increase in the area of water associated with a 3% increase in housing values and one extra hour of sun per month would increase housing values by 0.17%. Surprisingly, the proportion of the houses that are detached decreases median housing values. At first review this would seem counterintuitive as one would assume that a county with more single-family detached homes would be an indication of wealth and therefore command higher housing values. However, most likely this variable is capturing the effects of sprawl where more detached houses may be an indication of lower population density and therefore lower housing values. The positive coefficient for attainment cannot be interpreted as a preference for ozone as the attainment variable may not actually capture the ozone levels which citizens perceive. It does however provide evidence that neither the presence of ozone regulations and the possible high levels of ozone associated with those regulations are considered a disamenity.

Results in Table 7.3 show the same estimation, using mean ozone values instead of the attainment variable. As discussed in Chapter 4, the problems using ambient ozone data are not trivial. In this estimation 455 observations were dropped because of missing data for ozone. Nevertheless, the coefficient is negative but not significant which is a similar result as when the *kriged* value of ozone (as described in Chapter 4) is used in place of ambient ozone (results available on request)).

Table 7.2 Linear regression results explaining housing prices with Attainment variable, 1997

Dependent Variable Equation*	***LOGMED VAL***	**Std. Error**	***t-value***
ATMT	0.0674	0.0066	10.2234
TYPOG	0.0014	0.0016	0.8647
SUN	0.0017	0.0003	5.5095
WINTER	0.0007	0.0014	0.5510
LOGWATER	0.0303	0.0056	5.4239
LOGPSFIN	0.0668	0.0200	3.3322
LOGPSOTH	0.1705	0.0217	7.8624
LOGPOPGR	0.4590	0.0750	6.1235
RETIREAGE	-1.8786	0.2765	-6.7935
OWNER	0.2825	0.2630	1.0743
DETATCHED	-0.6425	0.1081	-5.944
MINORITY	-0.2812	0.0683	-4.1147
UIC	-0.0430	0.0101	-4.2730
CONSTANT	12.1022	0.1257	
Rsquared	0.7116		
N	831		

*Estimated with control variables *GEO* and *MSA*

Table 7.3 Linear regression results explaining housing prices using Ozone levels

Dependent Variable Equation	***LOGMED VAL***	**Std. Error**	***t-value***
OZONE	-2.2079	2.1449	-1.0294
TYPOG	0.0041	0.0028	1.5000
SUN	0.0017	0.0005	3.4069
WINTER	0.0032	0.0025	1.2948
LOGWATER	0.0462	0.0093	4.9785
LOGPSFIN	0.0724	0.0370	1.9539
LOGPSOTH	0.2602	0.0392	6.6462
LOGPOPGR	0.4360	0.1508	2.8916
RETIREAGE	-2.8340	0.4806	-5.8973
OWNER	0.0482	0.1381	0.3492
DETATCHED	-0.8439	0.1944	-4.3419
MINORITY	-0.2284	0.1147	-1.9904
UIC	-0.1073	0.0265	-4.0549
CONSTANT	12.4575	0.2275	
Rsquared	0.6868		
N	386		

*Estimated with control variables for *GEO* and *MSA*

A one-unit increase in ozone levels is associated with a 200% decrease in home values. However a one-unit increase in mean values, say from 0.06 to 0.07 ppm, is a very large increase. There is also undoubtedly selection bias because the counties that have ozone monitors are typically those counties with an ozone problem. That this coefficient is not significant at even the 90% level indicates we should interpret the results as only modest indication that the presence of ozone does indeed lower housing values. The other explanatory variables are consistent with the coefficients in from Table 7.2, most notably that the presence of sun and water can be expected to significantly increase values of housing.

Tables 7.4 and 7.5 shows the results of estimating Equation (7.2) which approaches the amenity question from a different angle. The hypothesis is that areas with lower levels of ozone will have a higher quality of life, *ceteris paribus,* and will experience inward migration leading to population growth. The regression results show little evidence to support the hypothesis. The positive relationship between the *ATMT* variable and population growth and can be interpreted as follows: as the severity of a county's ozone problem increases (*e.g.,* if the non-attainment status shifts from Moderate to Serious), the population growth could be expected to be 0.33%. As the coefficient is not significant, this result should be interpreted with caution. More relevant is the positive sign on the coefficient. The fact that a county fails to attain the ozone standard does not deter population growth.

Again, consistent with known population shifts to the Sun Belt, increases in hours of sunlight during winter months is an important determinant of population growth. That the presence of water is not a significant determinant of population growth might be an indication of 'crowding out.' Counties with large areas of water may have become so expensive so as to no longer be attractive destinations for amenity-seeking migrants.

The coefficient for *PSFIN* is interesting. It is natural that this variable would be positive and significant in explaining housing prices but it is not obvious that the financial services would also be a determinant of population growth. As a proxy for human capital, this is strong evidence that quality human capital attracts more of the same.

Table 7.4 Linear regression explaining population growth using Attainment variable, 1997

Dependent Variable Equation	***LOGPOP GR***	**Std. Error**	***t-value***
ATMT	0.0033	0.0032	1.0450
TYPOG	-0.0004	0.0008	-0.5394
SUN	0.0009	0.0001	6.4759
WINTER	0.0033	0.0006	5.1376
LOGWATER	-0.0004	0.0027	-0.1560
LOGPSFIN	0.050	0.0093	5.8898
LOGPSOTH	0.0076	0.0103	0.7388
OWNER	0.1988	0.0657	3.0236
RETIREAGE	-1.3272	0.1227	-10.8164
DETACHED	0.1005	0.0515	1.9538
MINORITY	-0.1830	0.0320	-5.7206
UIC	-0.0155	0.0048	-3.2290
CONSTANT	0.2393	0.0613	3.9060
Rsquared	0.4275		
N	831		

*Estimated with control variables for *GEO* and *MSA*

Perhaps more revealing is the positive coefficient when the *ATMT* variable is substituted for *OZONE* as presented in Table 7.5. Again, the coefficient is not significant so the interpretation must be simply that higher ozone levels are *not* a significant deterrent to a county's population growth. The coefficients for *PSFIN* for both estimations are revealing; the coefficient is positive and significant in both estimations indicating that counties with financial services are experiencing population growth. This is consistent with previous findings that the financial services sector is very likely to benefit from scale economies. The coefficients for *PSOTH* are less conclusive with a weakly positive, and negative coefficient in the two estimations.

Table 7.5 Linear regression explaining population growth using Ozone levels, 1997

Dependent Variable Equation*	***LOGPOP GR***	**Std. Error**	***t-value***
OZONE	0.4079	0.7494	0.5442
TYPOG	-0.0018	0.0009	-1.8998
SUN	0.0012	0.0002	7.0109
WINTER	0.0019	0.0009	2.2305
LOGWATER	-0.0058	0.0033	-1.7810
LOGPSFIN	0.0585	0.0124	4.7039
LOGPSOTH	-0.0259	0.0136	-1.9058
OWNER	0.2535	0.0915	2.7694
RETIREAGE	-1.3266	0.1521	-8.7201
DETATCHED	-0.0313	0.0680	-0.4610
MINORITY	-0.2120	0.0384	-5.5166
UIC	-0.0146	0.0093	-1.5683
CONSTANT	0.2480	0.0818	3.0328
Rsquared	0.5059		
N	386		

*Estimated with control variables for *GEO* and *MSA*

In all four estimations the results for the amenity values are consistent with our existing knowledge base about population shifts and value premiums for access to water and increased sunlight. The typography variable is negative in each estimation indicating a preference for lower values of the *TYPO* variable (lower values represent mountainous areas while the higher values represent flat plains). That this variable is not significant is revealing. Much like ozone, people may prefer to live in an area with an interesting typography, but this amenity is not as important relative to other considerations.

7.4 Conclusion

The results of this chapter are consistent with those of Kahn (2000a and 2001a) indicating that the absence of ozone may be considered an amenity but that relative to other economic and quality-of-life attributes of a place, ozone cannot be considered a significant disamenity. There are reasons to be cautious, however. The spatial scale of the hedonic regression analysis was much larger than has been used before. Typically housing values (or housing rents) are analyzed on the census tract or zip code level and include attributes such as number of rooms in the unit and unit size. The R-squared value of 0.67 did indicate that the regressions from Equation (7.1) captured a good proportion of the variation in the data.

The population growth equations (7.2), with a much lower R-squared value of 0.42 are nevertheless consistent with the stylized facts in urban economics *e.g.* that the suburbs are experiencing growth, especially those counties with a higher proportion of service-sector industries. The proportion of the population which is of retirement age is a strongly negative determinant of population growth. That is, an increase in retirees is associated with an overall decline in population. This most likely reflects retirees' preference for less densely-populated areas rather than a flight of the population away from traditional retirement areas.

It is also prudent to exercise caution when interpreting the coefficients of *OZONE*. As shown in Figure 4.6 the predicted ozone value has very little variability and the correlation coefficient between *ATMT* and *OZONE* is only 0.08. Nevertheless the variable is still significant at the 0.05% level in Equations (5.2) and (5.15). As the variable underestimates actual ozone values, it is plausible that the revealed preference for the absence of ozone is also understated. In other words, it is possible that ozone is more of a disamenity than is revealed in these regressions. However the reverse is also likely and any definitive conclusions should be deferred until a better prediction from ozone is calculated.

The difficulties in estimating the economic effect of ozone at a spatial level beyond the census tract or zip-code level are vast and while not insurmountable, require considerable time and effort in manipulating data and developing feasible models. The spatial and data issues inherent in this inquiry make it a fruitful area for future research. The many predictive tools available from geostatistics and other fields are just beginning to be applied and reveal a promising area of interdisciplinary research.

CHAPTER 8

CONCLUSION

8.1 Framework for policy discussion

The preceding chapters show that the unique characteristics of tropospheric ozone make it not only an interesting case study in environmental economics but also a challenging policy problem. Interacting effects of socio-economic trends as well as data constraints make conclusive analysis of the problem problematic. Nevertheless, it is useful to characterize the problem within the framework of the canonical "carrot" and "stick" analogy. Understanding the varying impact of the ozone attainment regulations for different economic sectors and within a gradient of characteristics of urban form can be useful in predicting the efficacy of certain regulatory actions (*i.e.*, the stick). For example, rules which may work to reduce ambient ozone levels in a densely populated metropolitan area may not be as efficacious in a newer Southwestern metropolitan area with an economic base that is primarily service-oriented and tied to the automobile.

The concept of the EKC is useful in understanding the mechanisms that might provide incentives for ozone reduction (*i.e.,* the carrot). When the absence of a pollutant is not considered to be an amenity, the typical mechanisms that would trigger a reduction in ambient pollution levels do not work. To consider how powerful the amenity part of the equation actually is, consider if the same problem persisted with a highly visible constituent such a Particulate matter (PM2.5). In spite of a recent increase in the stringency of this threshold from 10 ppm to 2.5 ppm, there are only 194 counties which fail to attain the PM2.5 standard, and most of these are in states with coal-fired power plants. Entire regions, including most of the Western U.S., and states typically associated with a high quality-of-life, are in compliance with the standard. While tropospheric ozone does contribute to smog, in most cases, its presence goes unnoticed by the general population. Only in rare cases do the levels reach high enough to be perceived as a disamenity, thus kick-starting into motion the economic mechanisms which will provide incentives for a reduction in ambient levels.

In addition, the distributed-nature of ozone emissions make it a classic problem of "the commons." This refers to a class of problems where there is a conflict over resources between individual and the common good. The analogy to ambient ozone pollution is that unrestricted, unregulated or relatively cost-free access to the atmosphere leads to overuse or abuse. An obvious and simplistic application of this idea is the growing prevalence of Sports Utility Vehicles (SUVs) in urban settings where individuals desire the perceived safety and convenience of and SUV while emitting far more pollutants than necessary for simple transport between places. This desire for larger vehicles has a negative effect on the common good by leading to increased automobile emissions. While the theory and practical implications of "the commons" problem is beyond the scope of this discussion, it is relevant because it highlights the conundrum for policy-makers.

The probability that dramatic reductions in ozone levels will occur in the areas where the ozone problem exists now is low. There are both supply and demand side reasons for this and I discussed the major reasons in Chapters 5 and 6. Aggregate emissions have declined substantially and the largest drivers of supply today are electricity generation and air and motor vehicle travel. Future estimates of emission reductions are predicated on technological innovations that will ensure that emissions per unit decline faster than our per unit consumption of electricity or travel. The demand side analysis concludes that the transition to a service economy concentrates high consumption individuals geographically, thus exacerbating the problem. Notably, the analysis focused on tradable services, reflecting the bias of an "export-oriented" perspective in regional economic analysis. Future work should include the non-tradable services to truly understand the dynamics of the interplay between metropolitan economic growth, urban form and ozone pollution.

The policy response to the ozone problem to date has focused on a “stick” mentality. This approach is effective when the pollutant is associated with a “nuisance” or disamenity factor (whether perceived or real). Technological “fixes” may indeed decrease emissions per unit. However, the predicted increases in VMT and electricity consumption mean that innovation must steadily continue. Technology-forcing regulations are an effective mechanism to encourage innovation in the marketplace. By setting an environmental standard more stringent than can be met by using existing technology, the rule creates a new economic imperative to “force” technological innovation and commercialize the next generation of advanced technologies. An even more formidable obstacle is the litigious relationship between industry, consumer groups and the EPA. While incremental decreases in ozone levels are likely based on the pattern we have seen in the past 30 years, the “stick” approach to ozone control will only have limited efficacy. If we can understand what will drive the demand for the absence of ozone we will be more likely to formulate effective “carrot” policies that more effectively reduce ozone polluting activities.

7.2 Implications of amenity factor for ozone regulation

Much can be learned from the experiences of California counties where Kahn (2001) has shown that declining ozone levels, holding all other housing amenities constant, had a positive effect on housing prices. The benefits are modest and incremental, however as the Los Angeles Metropolitan area remains in the “Extreme” category of non-attainment and is not predicted to meet the standard until 2021. However, the promise of applying lessons of counties which entered the “Extreme” category cannot be a panacea, or even a model, for ozone control. In the extreme category counties will have a serious smog problem, which then becomes a tangible and undesirable characteristic. Very few counties even enter into the extreme category of non-attainment with most counties at the moderate level and may experience numerous smoggy days, especially in the hot summer months. Nevertheless, relative to the other benefits of living in these areas (*i.e.,* higher wages), smog may be an acceptable trade-off.

Assuming the economic structure and physical form of U.S. counties will not change dramatically over the next decade and assuming that reaching extreme levels of ozone levels as many areas in the U.S. experienced in the 1990s it is intriguing to consider what we an expect future ozone levels in U.S. metropolitan areas to look like. Recall Figures 1.2 and 1.3, repeated here as Figures 8.1 and 8.2. These show how citizens might be expected to react when confronted with very high ozone levels at relatively high levels of income. This is analogous to the Los Angeles case study (Kahn 2003) where the important point is that citizens actually perceive the ill effects of ozone, either through extensive education campaigns that detail the harmful side effects of exposure to ozone and/or through physically experiencing ill effects of

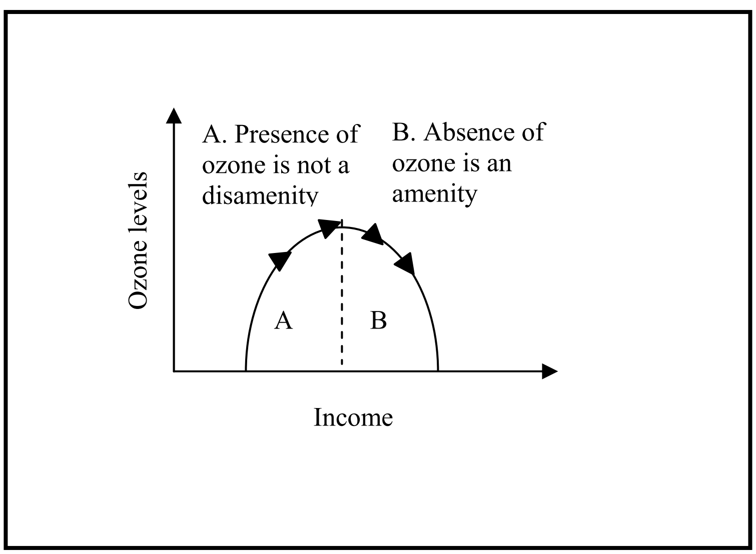


Figure 8.1 Hypothetical EKC when absence of ozone is an amenity

ozone, either through visualizing smog or experiencing respiratory difficulties, or both.

Figure 8.2 is a hypothetical illustration of what a modified EKC might look like at the point where ozone becomes imperceptible, or at least a relatively modest inconvenience relative to other quality-of-life offerings. This analysis shows this is the steady-state into which many metropolitan counties are entering, with little hope of significant reductions in ozone in the foreseeable future.

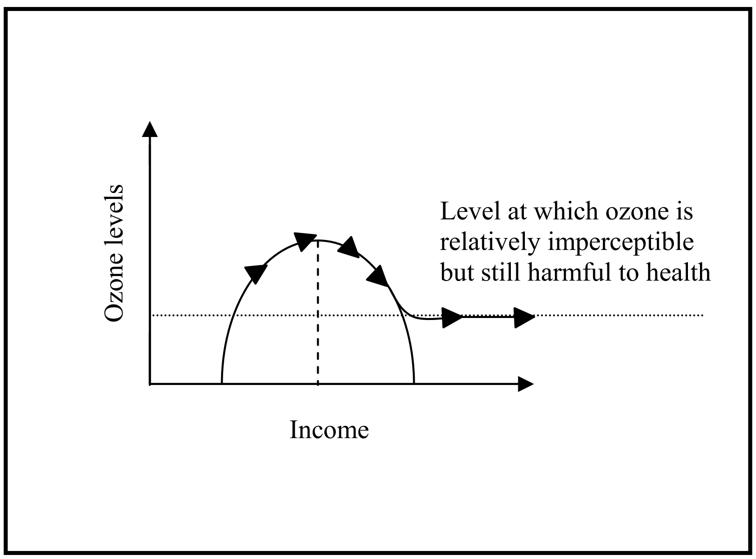


Figure 8.2 Hypothetical EKC when absence of ozone is not considered an amenity

The issue then becomes a matter for public policy debate as to whether there are sufficient risks to human health to warrant a more sophisticated education campaign to alter the public's perception of high ozone levels. Is there sufficient evidence to advance a claim that the absence of ozone should be considered an amenity? What are the trade-offs in terms of economic development? Most likely the regulatory framework will continue to co-develop with current scientific understanding and public education, thus creating an iterative process of increasingly stringent regulatory and public tolerance threshold values. As perception of the problem changes so to will the demand for even cleaner air, resulting in higher standards.

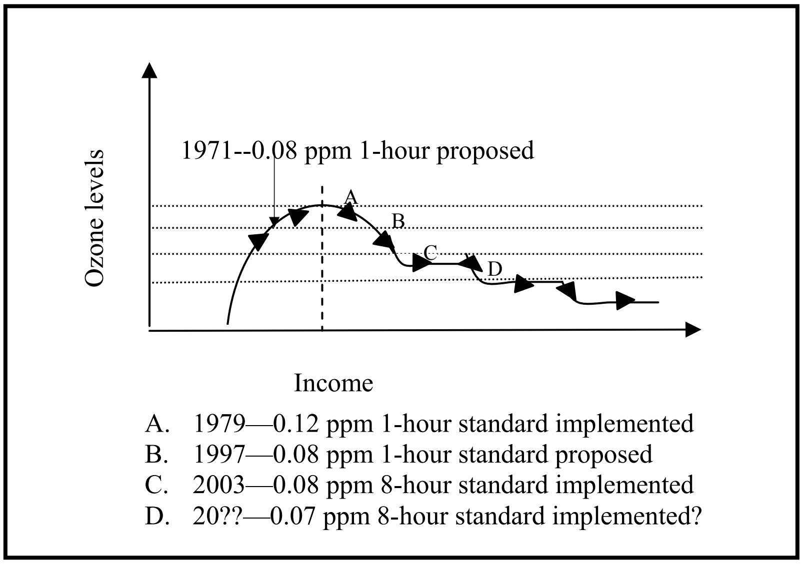


Figure 8.3 Hypothetical inverse S-curve based on regulatory history and data analysis

8.4 Understanding implications for developing countries

The policy implications for developing countries are immediate and simple. Knowledge that citizens will not perceive ozone as deleteriously as other more seemingly noxious pollutants means that education must be started early in the environmental regulation process. As awareness of environmental problems grew in the 1970's, the U.S. had a plethora of very serious air and water quality problems to consider. Naturally, the problems deemed most serious were addressed first. Lead, carbon dioxide and particulate matter pollution was tangible and public support for regulations were strong. Although ozone was originally included in the constituent pollutants regulated by the Clean Air Act, the 1-hour monitoring threshold was set too high at 0.12 ppm. The issue did not receive serious attention until 1991 when new scientific evidence revealed the serious affect of elevated ozone levels on human health. The American Lung Association sued the EPA but even in 1991, 371 counties failed to attain the more liberal standard. The threshold level was reduced to 0.08 ppm in 1997 but the mechanisms for reduction of NOx and VOCs emissions were not fully-developed making a quick transition into compliance with the new standard nearly impossible. As the regulatory requirement has become even stricter, moving to the 8-hour standard in 2003, most noncompliant counties were unable to adjust and continue to fail to achieve the standard.

We have only recently begun to understand the long-term effects of sustained exposure to ozone and there are further calls to tighten the standard again. In spite of significant efforts by the EPA to publicize these findings, the public's appetite for absorbing this information seems weak. This analysis showed that even if the public does understand the risks, they might be willing to accept the risk as a tradeoff for other amenities or benefits. The seemingly almost harmless nature of ozone has led to complacency among the U.S. population. It is this complacency that will make achieving further reductions more difficult than it needs to be.

With the benefit of the U.S. experience and updated scientific knowledge, developing countries can ensure that ozone is included within the suite of pollutants whose emissions are regularly measured and controlled through regulatory or voluntary incentives. By 2007 the international community has become aware of the effects of air pollution, both in terms of human health and economic performance. Active and aggressive pollution control campaigns exist in many major global metropolitan areas and ozone is counted as a significant criteria pollutant for monitoring and control. It is possible that by coupling ozone with other more tangible constituent pollutants very early in education and regulatory campaigns that the “absence of ozone” will become an amenity more quickly as income levels rise than it did in the U.S.

7.3 Future work

There are many open questions from this analysis. Perhaps the most important is at what level does ozone transition from being a disamenity (where the threat to health is actually perceived or there is a significant negative aesthetic) to simply another factor that consumers evaluate when judging the attractiveness of an area?

The implications of the clustering results in the context of ozone regulations are important not as results which can be transformed into absolute policy prescriptions but as predictors of future trends that must be taken into account in planning. Given the strong association between producer services and ozone non-attainment, the evidence that the *PSOTH* and *PSFIN* are clustering hints at serious challenges for those counties where relatively high levels of producer services already exist.

Analysis of both questions would be greatly enhanced by incorporating the non-traded sector of the economy. While the sectors chosen here clearly represent some of the drivers of economic growth, they are not the only drivers of growth in metropolitan and regional economies and the relationship to ozone levels is still unknown.

APPENDIX A

Industry Composition of Six Traded Goods & Services (Source: Drennan, 1999)

Category	SIC Code*
Manufacturing (MFG)	
Food & kindred products	20
Tobacco	21
Textiles	22
Apparel	23
Lumber & Wood Products	24
Furniture & fixtures	25
Paper & allied products	26
Printing & publishing	27
Chemicals & allied products	28
Petroleum & coal products	29
Rubber & miscellaneous plastic products	30
Leather & leather products	31
Stone, clay & glass products	32
Primary metals	33
Fabricated metals	34
Industrial machinery & equipment	35
Electronic & other electrical equipment	36
Transportation equipment	37
Instruments & related products	38
Miscellaneous manufacturing	39
Distribution (DIST)	
Railroad transportation	40
Trucking & warehousing	42
Water transportation	44
Transportation by air	45
Pipelines except natural gas	46
Wholesale trade	50-51
Financial Producer Services (PSFIN)	
Depository institutions	60
Nondepository institutions	61
Security & commodity brokers	62
Insurance carriers	63
Insurance agents & brokers	64
Real estate	65
Holding & other investment offices	67
Other Producer Services (PSOTH)	
Communication	48
Business services	73
Legal services	81
Engineering & management services	87
Services not elsewhere classified	89
Advanced Consumer Services (ACS)	
Motion pictures	78
Amusement & recreation services	79
Health services	80
Educational services	82
Museums, botanical, zoological gardens	84

*Note SIC codes were replaced by NAICS codes in 2001

APPENDIX B

PREDICTING AIR QUALITY DATA

Spatial data problems can occur when there is a mismatch between the geographic area in which the data is collected. This is called the *spatial support.* The spatial support problem, including the issues of matching point to area data (most common in this context) and making inferences about missing data can be addressed through the use of kriging. There are two issues to be considered. The first is multiple monitoring point observations within one county and the second is missing observations for many of the metropolitan counties (more than 200 metropolitan counties do not have monitoring sites). Complete data coverage is important because of the risk of identification bias; the ozone monitors are placed in areas specifically because there is already an ozone problem and there may be no monitors in areas where the ozone problem is minimal.

Kriging uses prior knowledge about the spatial distribution of ozone and this knowledge captures how ozone levels co-occurs as a function of space. The covariance structure between spatially disjoint monitoring observations can both realign the point-level ozone measure to the county (area) level and predict ozone levels in areas where monitors do not exist. While the method has limitations (revealed in the analysis below) it is currently the best available technique and has been used by the EPA for various internal analyses (personal communication 2000).

More specifically, Kriging is a family of linear least squares estimation algorithms where the end result obtains the conditional expectation as a best estimate for all unsampled locations in a field and consequently, a minimized error variance at each location. The process of kriging begins with the estimation of an empirical variogram which is a function of the random process Z:

$$\mathrm{var}(Z(s_1) - Z(s_2)) = 2\gamma(s_1 - s_2),\ \forall\ s_1, s_2 \in D, \qquad \text{(B.1)}$$

where s is an index of known spatial locations $\{ s_1 \ldots s_n\}$ which vary continuously through the region D and D is a subset of $\Re^d$ with positive d-dimensional volume (Cressie, 1993).

The conditional expectation minimizes the error variance when the optimality criterion is based on least squares residuals. The Kriging estimate is a weighted linear combination of the data and the weights that are assigned are determined by solving the Kriging system of linear equations, where the weights are the unknown regression parameters. As mentioned above, the optimization technique is a minimization of the least-squares error variance. For this estimation $\{ s_1 \ldots s_n\}$ represents the vector of *ARITHMEAN* values for each monitoring site. Rewriting the system of linear equations:

$$E(Z(\mathrm{s} + \mathbf{h}) - Z(\mathrm{s})) = 0, \qquad \text{(B.2)}$$

$$\mathrm{var}(Z(\mathrm{s} + \mathbf{h}) - Z(\mathrm{s}))=2\ \gamma(\mathrm{h}). \qquad \text{(B.3)}$$

The variogram is used to fit a model of the spatial correlation of the observed data. There is an important distinction between the empirical variogram that is a visualisation of a spatial correlation and the variogram model that is further used to define the weights of the kriging function. The empirical variogram is an empirical estimate of the covariance of a Gaussian process. As such, it may not be positive definite and is not used in kriging. A limited number of variogram models such as linear, spherical, gaussian and exponential models, are the most frequently used (Haining 1990).

The variogram function in Splus 2000 provides two estimators of the variogram, the classical (Matheron 1962 in Cressie 1993) and the robust method

(Cressie and Hawkins 1980 in Cressie 1993). The classical estimator is unbiased but does not handle outliers well:

$$2\tilde{\gamma}(\mathbf{h}) \equiv \frac{1}{|N(\mathbf{h})|}\sum_{N(\mathbf{h})}(Z(\mathbf{s}_i) - Z(s_j))^{1/2}, \tag{B.4}$$

where $N(\mathbf{h}) \equiv \{(i,j) : \mathbf{s}_i - \mathbf{s}_j = \mathbf{h}\}$ and $|N(\mathbf{h})|$ is the number of elements in

The robust estimator reduces the effect of the outliers without having to remove them from the dataset. The robust estimator used in this study is as follows:

$$2\,\hat{\gamma}(\mathbf{h}) = \left\{\frac{1}{|N(\mathbf{h})|}\sum_{N(\mathbf{h})}\left|Z(s_i) - Z(s_j)\right|^{1/2}\right\}\Big/(0.457 + \frac{0.494}{|N(\mathbf{h})|} \tag{B.5}$$

Frequently, the process Z will not be purely a function of distance between two spatial locations but a function of the magnitude and the direction of **h** because the underlying physical process evolves differently across space. This is called anisotropy. Ozone data is likely to exhibit anistropy because of the many factors unrelated to the actual emission of NOx and VOCs, which affect distribution of pollutants. Some examples of these exogenous factors are wind, geographic formations which either trap or disperse ozone, and variations in intensity of sunlight across the U.S. Figures B.1 and B.2 depict omnidirectional empirical variograms for the variable *ARITHMEAN* using the classical and robust methods, respectively. The variogram is plotted as a function of distance and γ for four different azimuth[12] (0, 45, 90, 135) and four different ratios of the major to minor axes of the ellipse (1.25, 1.5, 1.75 and 2.0).

[12] The azimuth is defined as the horizontal component of a compass direction measured around the horizon from the North point, toward the East, i.e. clockwise. It is usually measured in degrees.

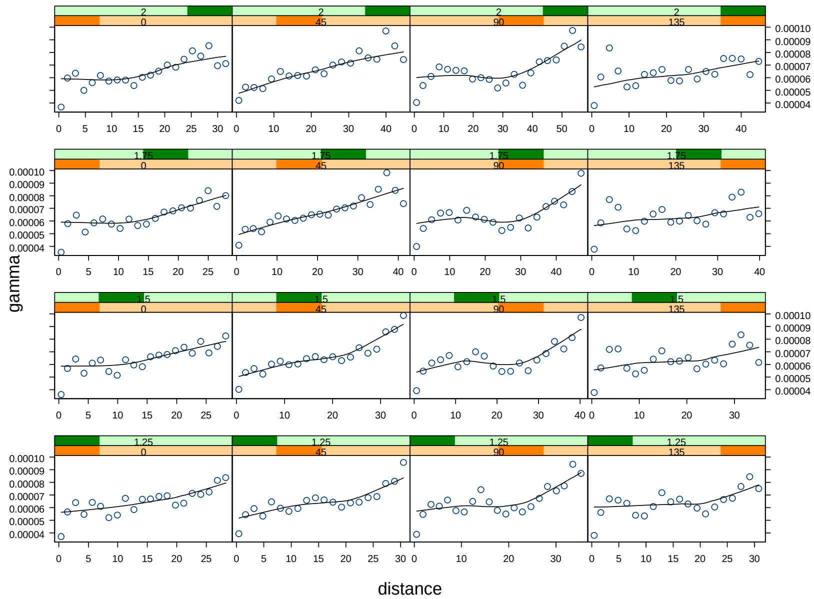


Figure B.1 Omnidirectional variogram using classical variogram estimator

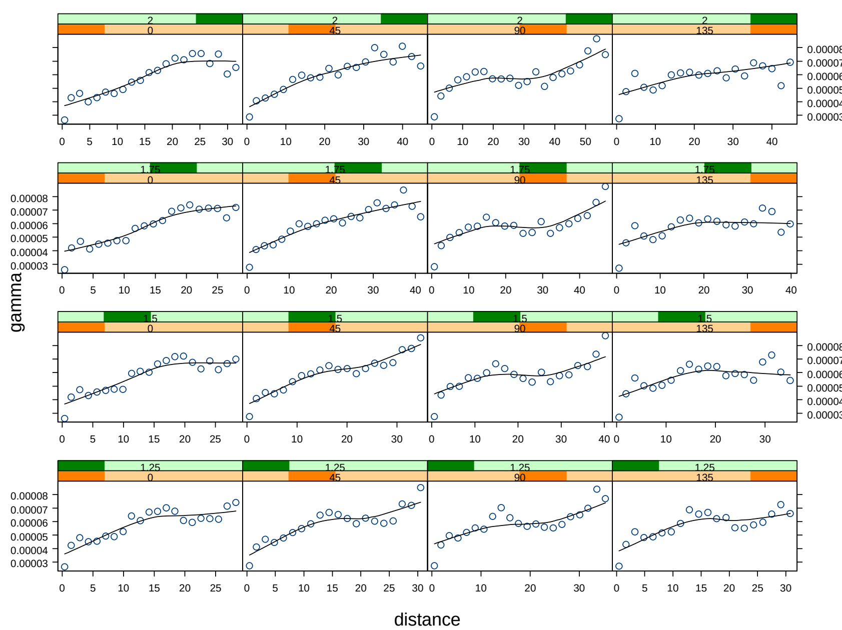


Figure B.2 Omnidirectional variogram using robust variogram estimator

All variograms are defined by three parameters, the nugget, sill and range. The nugget is estimated as $2\gamma(h)$ in Equations B.6 and B.7 and the sill is the $\lim_{h\to\infty} \gamma(h)$ representing the variance of the random field. The range is the distance (if any) at which the data are no longer autocorrelated (Kaluzny *et al.* 1998). Graphically, the nugget is the point at which the fitted line intersects the y-axis, the sill is the inflection point, if any, at which the covariance structure dissipates into randomness and the range is the spatial distance at which this occurs. The most obvious observation when reviewing the two plots depicting the classical and robust estimations is in Figure B.4 the effects of outliers are not as prominent as they are in Figure B.3. The nugget effect in Figure B.4 is approximately 0.0006 but approximately 0.0004 in Figure B.3. The sill is difficult to estimate from Figure B.5 but is approximately 0.0007 in the robust estimation. Likewise, the range using the classical estimation is difficult to determine but appears to be between 10 and 20 using the robust estimator.

Both variograms suggest a directional trend in the east-west direction (azimuth=90), an indication of geometric anisotropy. This is not surprising since most of the data is collected near the coastal areas where we would expect strong effects from coastal winds. Splus 2000 corrects for anisotropy by removing the east-west trend. The omnidirectional empirical variogram using robust estimation but without a correction for anisotropy is shown in Figure B.3:

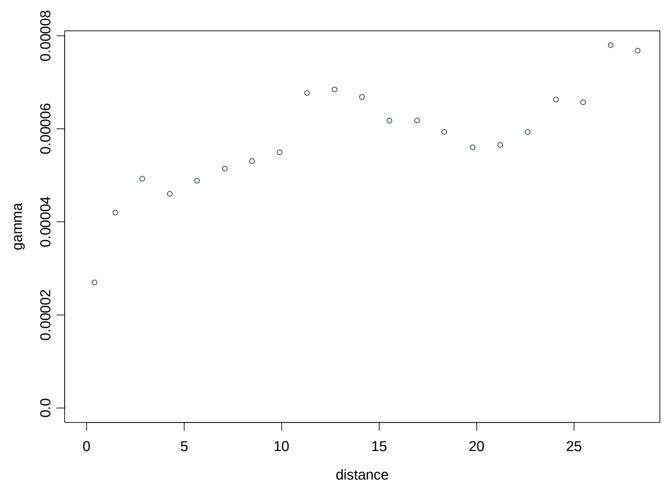


Figure B.3 Omnidirectional variogram without anisotropy correction

The range is difficult to determine as it is not clear that there is a distance at which the data fails to be autocorrelated. The same variogram is again estimated setting the maximum distance at 12:

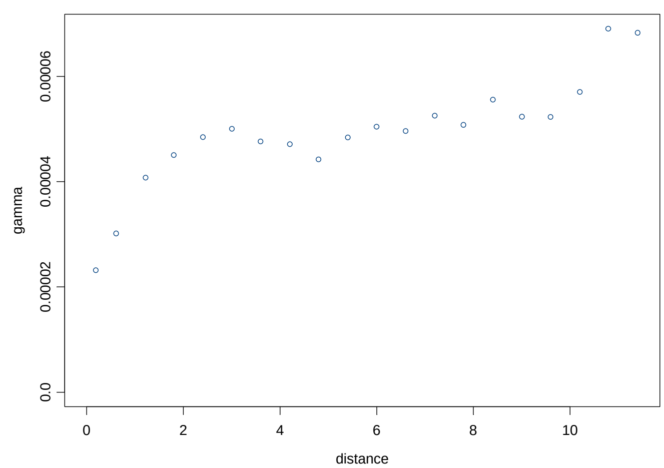


Figure B.4 Omnidirectional Variogram with Maximum Distance of 12

Correcting for the trend in the 90 degree azimuth the variogram which approximately has a nugget of 0.0004, a sill of approximately 0.00075 and a range of 5.0 to 5.5.

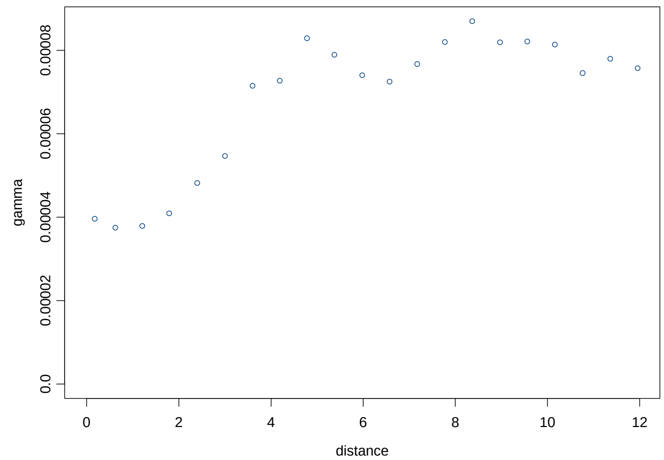


Figure B.5 Omnidirectional Variogram with correction for Geometric Anisotropy

As mentioned earlier, the empirical variogram cannot be used for spatial prediction because it is not necessarily negative-definite. Therefore it is necessary to find a model variogram which most closely represents the spatial dependence in the data and further defines the spatial weights. The observed relationship can be exponential, spherical, gaussian, a power function or linear. After experimentation, the spherical model appears to have the best fit to the data and Splus 2000 fit the theoretical variogram model to the defined empirical variogram (as depicted in Figure B.5) using generalized least squares (GLS). GLS minimizes the sum of squares between uses the second-order structure of the variogram estimator and does not make assumptions about the whole distribution of the data. It is this variogram that is used in kriging. Figure B.6 shows the empirical variogram plotted together with the theoretical variogram model:

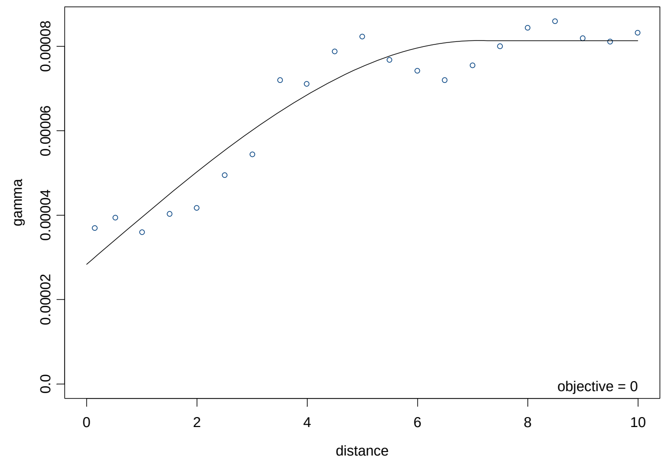


Figure B.6 Omnidirectional Variogram with Spherical Variogram Model

Taken from Cressie (1993), the variogram model is used to predict ozone mean values by making inferences about unobserved values in the random process $Z(\mathrm{s})$ where $\mathbf{s} \in D$. A generic predictor of $g(\mathrm{Z}(\cdot))$ is

$$p(\mathbf{Z};\, \mathrm{g}). \tag{B.8}$$

The geometry and location will determine the best predictor. When $g(\mathrm{Z}(\cdot))=Z(B)$ then equation (6) can be written as $p(\mathbf{Z};\, B)$. The two types of kriging are ordinary kriging and universal kriging. Ordinary kriging assumes a constant mean model where

$$Z(\mathrm{s}) = \mu + \delta(\mathrm{s}), \quad \mathrm{s} \in D\,,\; \mu \in \Re,\; \mu \text{ is unknown} \tag{B.9}$$

and $\delta(\cdot)$ is a zero-mean stationary random process using variogram $2\gamma(\cdot)$. The assumption in predicting $Z(\mathrm{B})$ from $\mathbf{Z}$ is highly restrictive assuming that the coefficients of the linear predictor sum to 1:

$$p(\mathbf{Z}; B) = \sum_{i=1}^{n} \lambda_i Z(\mathbf{s}_i), \quad \sum_{i=1}^{n} \lambda_i = 1. \tag{B.10}$$

In universal kriging the assumption changes such that the zero-mean random process is no longer constant but an unknown linear combination of known functions denoted as $\{f_0(s), \ldots f_p(s)\}$, $s \in D$. Inserting this less-restrictive assumption on μ into Eq. (B.7),

$$Z(\mathbf{s}) = \sum_{j=1}^{p+1} f_{j-1}(\mathbf{s})\beta_{j-1} + \delta(\mathbf{s}), \;\; \mathrm{s} \in D, \tag{B.11}$$

Where $\delta(\cdot)$ is a zero-mean stationary random process using variogram $2\gamma(\cdot)$ and $\boldsymbol{\beta}$ is an unknown vector of parameters. The prediction assumption for universal kriging then becomes a variation of Eq. (B.10):

$$p(\mathbf{Z}; B) = \sum_{i=1}^{n} \lambda_i Z(\mathbf{s}_i), \text{ for } \boldsymbol{\lambda}' X = \mathbf{x}'. \tag{B.12}$$

The universal kriging procedure in Splus 2000 using the spherical theoretical variogram minimizes the mean squared prediction error. As discussed earlier the data is gathered from ozone monitoring sites that have a unique geographic location identified by latitudinal and longitudinal measurements. The purpose of kriging is to predict ozone *PREDMEAN* values for each county, with only one data point per county. The kriged values are then predicted onto a new variable, *PREDMEAN,* comprising all counties identified uniquely by the latitude and longitude values for the county centroid.

APPENDIX C

There are two standard tests for the presence of spatial dependency, the Moran *"I"* and the Geary *"C"* coefficients. The statistics are evaluated on the basis of one of two assumptions, the normality or the randomization assumption called "free" and "nonfree," respectively. Free sampling assumes that the sample set of *n* observations is drawn from *n* independent drawings from a normal population whereas with randomization, the observations are one possible arrangement of *n* values. The latter is the appropriate assumption in this case because we have no reason to assume that the location of the counties in our dataset is normal. The "*I"* and "*C"* coefficients for both sets of regressions are both significant ($p<0$), indicating the presence of spatial correlation.

To control for the presence of spatial autocorrelation, I use a spatial linear model with an SAR (simultaneous autoregressive) covariance matrix. In this model the covariance matrix is defined as follows where *S* is the covariance matrix of a vector y of spatially correlated dependent variables and *W* is a diagonal matrix of weights:

$$S = ((I - \rho N)^t W^{-1} (I - \rho N))^{-1} \sigma^2$$

where ρ is a scalar parameter to be estimated and σ is a also a scale parameter to be estimated. *N* is the spatial neighbor matrix calculated with ArcView 3.2 using the Adjusted First Order method. A first order adjacency matrix is calculated where county *a* is given value "1" if is is adjacent to county *b* and "0" if it is not. Next, this matrix is 'adjusted' based on the following algorithm, an average (centroid-to-centroid) distance between the neighboring county and county *b* is calculated. A polygon not among those defined as neighbors already will be admitted as a neighboring polygon if it's spatial distance (centroid-to-centroid) from county *a* to county *b* is less than this average distance. The element x[*a,b*] of the weight matrix X is “1” if county *a* is a neighbor of polygon ***b*** under the above criteria, and is “0” otherwise.

This method is more flexible and preferable to the first order adjacency matrix because there are many cases when a county *a* may be a short distance from a given polygon *b* without sharing a boundary with it. The simple spatial neighbor criteria may fail to capture this kind of significant spatial relationship. The Adjusted First Order Method is also preferable to a pure distance matrix for several reasons. First, county sizes differ significantly across the US making it difficult to set objective criteria (a standard distance) across which we expect spillover to occur. In addition, the mod*e* of transport may also differ geographically. For example, in California, where most commuters travel by private automobile, we can expect the commuting distances to be greater than the congested Northeastern states where more commuting is by public transportation.

Inserting equations provides the SAR regression model:

$$Log(MedVal) = \alpha + X\beta + \gamma N(y - X\beta) + W^{-1/2}\varepsilon$$

ε is a vector error terms. Likewise, Equation (5.2) can be rewritten:

$$Log(POPGR) = \alpha + X\beta + \gamma N(y - X\beta) + W^{-1/2}\varepsilon$$

APPENDIX D

The first test for spatial randomness defines a point-to-point nearest neighbor statistic G where we define a distance d_i as the distance from the ith point to the nearest other point in the bounded region of interest A.

$$\widehat{G}(y) = n^{-1} \sum_{d_i \leq y} 1 \ ;$$

where n is the number of points in A. The resulting distribution function is plotted as a function of distance. Plots with a large number of small distance neighbors are an indication of spatial clustering while a large number of long distance neighbors indicate spatial regularity.

The second test of spatial randomness, the F test overlays a k x k grid on the region A and compares the m resulting origins to their nearest neighbor. The EDF is:

$$\widehat{F}(x) = m^{-1} \sum_{e_i \leq x} 1 \, ;$$

where e_i is the distance from the ith origin to the closest of the n points in A. Evaluation of the $\widehat{F}$ distribution function is opposite of $\widehat{G}$ with greater numbers of high distances indicating clustering and smaller numbers of shorter distances indicating apparent spatial regularity. As noted earlier, in both cases edge effects are ignored since these effects are most likely to be a problem only for small n or in the case of elongated polygons (Cressie 1993; Kaluzny *et al.* 1998).

Growth rates of each sector over two different time periods, 1977-1982 and 1992-1997 are calculated. The results show modest evidence of spatial clustering and are consistent with the correlation results: two sectors, advanced consumer services and manufacturing showed more spatial regularity in the latter time period while the producer services exhibited tighter clustering behavior relative to the 1977-1982 results.

The table below shows the empirical values of the respective distribution functions for both $\widehat{F}$ and $\widehat{G}$. The fixed distance values were arbitrarily chosen to compare the differing values of the distribution function and the growth rates for each sectoral shares are represented by the share name followed by *"GR"* (*eg., MFGGR)* to ensure the reader differentiates the growth rates from the normal share values. To interpret the results for $\widehat{F}$, recall that greater numbers of high values indicate clustering. Reviewing Table 4.5 the results for $\widehat{F}$ are very similar to the first grouping of tests (a) or those which exhibited positive growth in the sectoral shares over the two time periods. The values range from 0.59 to 0.87 with little variation between the sectors and the time periods. Evaluation of values for $\widehat{G}$ is more intuitive with greater numbers of low values indicating clustering. Reviewing the results in (a) there is some evidence that all sectors except *PSFINGR* showed less evidence of clustering in the later period. Comparing values for 1997 it is clear that *MFGGR* is the sector with the weakest evidence for clustering.

Results for Tests for Spatial Randomness

(a) Sectoral Share Results for Growth Rates > 0

		Distance	*Manufacturing Growth (MFGGR)*	*Advanced Consumer Services Growth (ACSGR)*	*Producer Services Financial Growth (PSFINGR)*	*Producer Services Other Growth (PSOGR)*
1977-1982	Fhat	0.1	0.59	0.67	0.61	0.63
		4.0	0.89	0.87	0.86	0.87
1992-1997	Fhat	0.1	0.59	0.64	0.64	0.64
		4.0	0.85	0.87	0.87	0.87
1977-1982	Ghat	0.5	0.78	0.84	0.75	0.85
		1.0	0.97	0.98	0.96	0.97
1992-1997	Ghat	0.5	0.73	0.79	0.81	0.81
		1.0	0.96	0.98	0.98	0.98

(b) Sectoral Share Results for Growth Rates > 50

		Distance	MFGGR	ACSGR	PSFINGR	PSOTHGR
1977-1982	Fhat	0.1	0.31	0.44	0.24	0.39
		4.0	0.85	0.81	0.75	0.84
1992-1997	Fhat	0.1	0.56	0.59	0.63	0.63
		4.0	0.80	0.85	0.84	0.89
1977-1982	Ghat	0.5	0.30	0.60	0.26	0.57
		1.0	0.73	0.88	0.64	0.88
1992-1997	Ghat	0.5	0.30	0.30	0.34	0.37
		1.0	0.76	0.75	0.75	0.85

(c) Sectoral Share Results for Relative Growth Rates > 50%

		Distance	RGMFGP	RGACS	RGPSFIN	RGPSOTH
1977-1982	Fhat	0.1	0.56	0.44	0.61	0.61
		4.0	0.89	0.81	0.89	0.87
1992-1997	Fhat	0.1	0.56	0.55	0.63	0.63
		4.0	0.84	0.84	0.86	0.86
1977-1982	Ghat	0.3	0.20	0.17	0.27	0.17
		0.5	0.74	0.61	0.74	0.83
		1.0	0.96	0.89	0.96	0.96
1992-1997	Ghat	0.3	0.19	0.17	0.26	0.24
		0.5	0.67	0.67	0.75	0.73
		1.0	0.96	0.94	0.99	0.99

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